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HAWKINS

ELECTRICAL GUIDE

NUMBER FIVE

QUESTIONS ANSWERS & ILLUSTRATIONS

A PROGRESSIVE COURSE OF STUDY
FOR ENGINEERS, ELECTRICIANS, STUDENTS
AND THOSE DESIRING TO ACQUIRE A
WORKING KNOWLEDGE OF

ECTRICITY AND ITS APPLICATIONS

A PRACTICAL TREATISE

by

HAWKINS AND STAFF

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CHAPTER XLVI

ALTERNATING CURRENTS

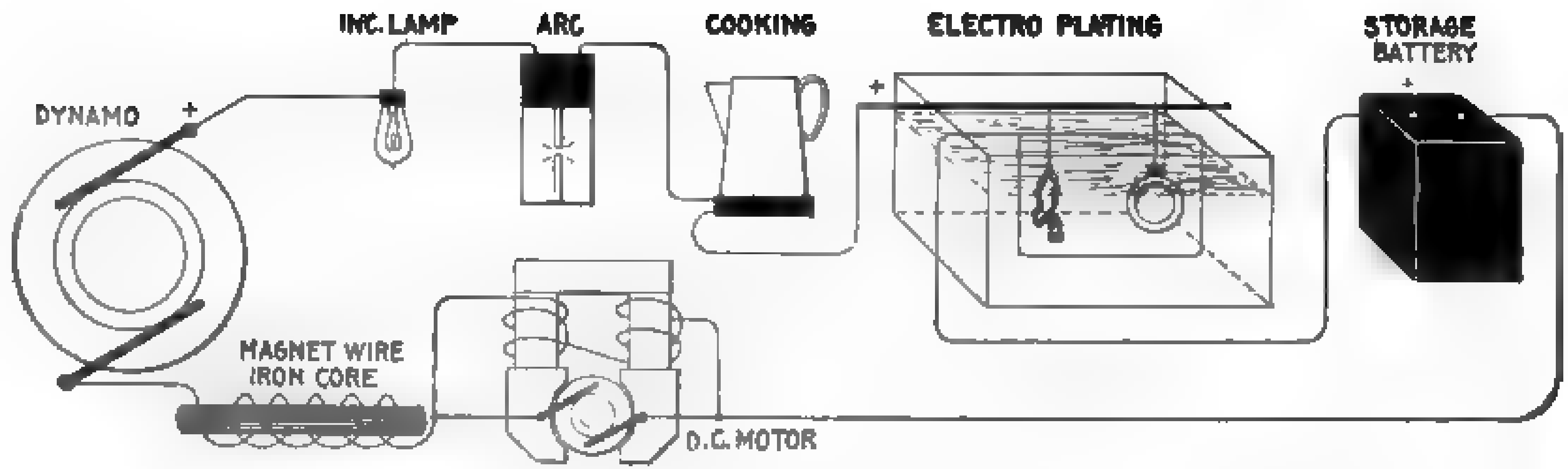
The word "alternating" is used with a large number of electrical and magnetic quantities to denote that their magnitudes vary continuously, passing repeatedly through a definite cycle of values in a definite interval of time.

As applied to the flow of electricity, an alternating current may be defined as: *A current which reverses its direction in a periodic manner, rising from zero to maximum strength, returning to zero, and then going through similar variations in strength in the opposite direction;* these changes comprise the *cycle* which is repeated with great rapidity.

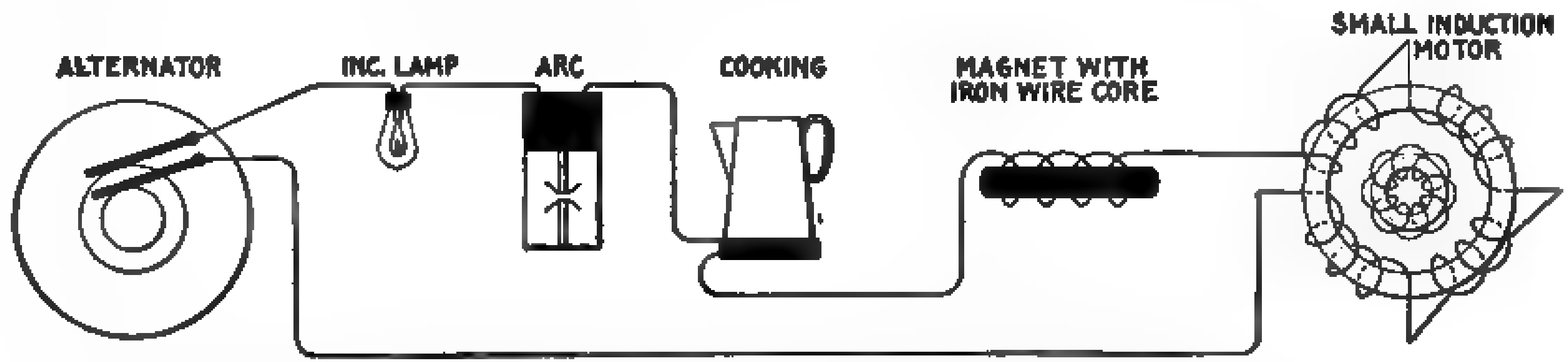
The properties of alternating currents are more complex than those of continuous currents, and their behavior more difficult to predict. This arises from the fact that the magnetic effects are of far more importance than those of steady currents. With the latter the magnetic effect is constant, and has no reactive influence on the current when the latter is once established. The lines of force, however, produced by alternating currents are changing as rapidly as the current itself, and they thus induce electric pressures in neighboring circuits, and even in adjacent parts of the same circuit. This inductive influence in alternating currents renders their action very different from that of continuous current.

Ques. What are the advantages of alternating current over direct current?

Ans. The reduced cost of transmission by use of high voltages and transformers, greater simplicity of generators and motors



FIGS. 1,206 to 1,212. Apparatus which operates successfully on a direct current circuit. The direct current will operate incandescent lamps, arc lamps, electric heating apparatus, electro-plating and typing bath, direct current motors; charge storage batteries, produce electro-chemical action. It will flow through a straight wire or just as freely through the same wire when wound over an iron bar.



FIGS. 1,213 to 1,217.—Apparatus which operates successfully on an alternating circuit. The alternating current will operate incandescent lamps, arc lamps, electric heating apparatus, alternating current motors. It will flow through a straight wire with slightly increased retarding effect, but if the wire be wound on an iron bar its strength is greatly reduced.

facility of transforming from one voltage to another (either higher or lower) for different purposes.

The size of wire needed to transmit a given amount of electrical energy (watts) with a given percentage of drop, being *inversely proportional to the square of the voltage employed*, the great saving in copper by the use of alternating current at high pressure must be apparent. This advantage can be realized either by a saving in the weight of wire required, or by transmitting the current to a greater distance with the same weight of copper.

In alternating current electric lighting, the primary voltage is usually at least 1,000 and often 2,000 to 10,000 volts.

Ques. Why is alternating current used instead of direct current on constant pressure lighting circuits?

Ans. It is due to the greater ease with which the current can be transformed from higher to lower pressures.

Ques. How is this accomplished?

Ans. By means of simple transformers, consisting merely of two or more coils of wire wound upon an iron core.

Since there are no moving parts, the attention required and the likelihood of the apparatus getting out of order are small. The apparatus necessary for direct current consists of a motor dynamo set which is considerably more costly than a transformer and not so efficient.

Ques. What are some of the disadvantages of alternating current?

Ans. The high pressure at which it is used renders it dangerous, and requires more efficient insulation; alternating current cannot be used for such purposes as electroplating, charging storage batteries, etc.

Alternating Current Principles.—In the operation of a direct current generator or *dynamo*, as explained in Chapter XIII, alternating currents are generated in the armature winding

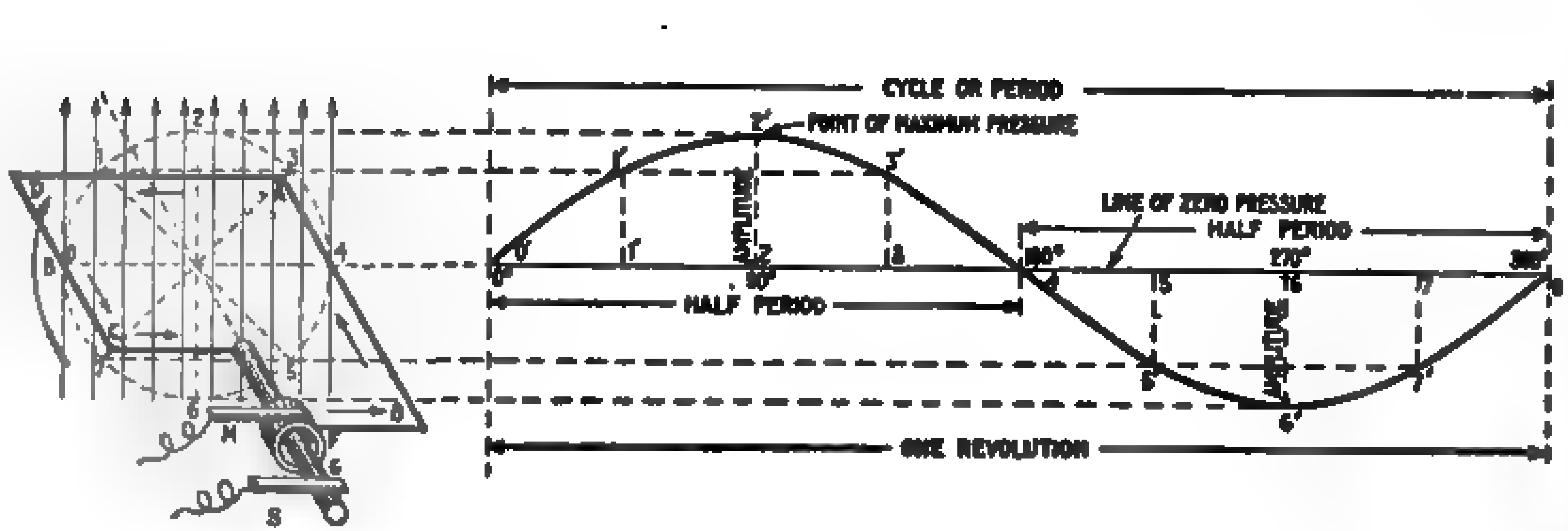


FIG. 1,216.—Application and construction of the sine curve. The sine curve is a wavelike curve used to represent the changes in strength and direction of an alternating current. At the left of the figure is shown an elementary alternator, consisting of a loop of wire ABCD, whose ends are attached to the ring F, and shaft G, being arranged to revolve in a uniform magnetic field, as indicated by the vertical arrows representing magnetic lines at equi-distances. The alternating current induced in the loop is carried to the external circuit through the brushes M and S. The loop, as shown, is in its horizontal position at right angles to the magnetic field. The dotted circle indicates the circular path described by AB or CD during the revolution of the loop. Now, as the loop rotates, the induced electric pressure will vary in such a manner that *its intensity at any point of the rotation is proportional to the sine of the angle corresponding to that point.* Hence, on the horizontal line which passes through the center of the dotted circle, take any length as 08, and divide into any number of equal parts representing fractions of a revolution, as 0°, 90°, 180°, etc. Erect perpendiculars at these points, and from the corresponding points on the dotted circle project lines (parallel to 08) to the perpendiculars; these intersections give points, on the sine curve, for instance, through 2 at the 90° point of the revolution of the loop, and projecting over to the corresponding perpendicular gives 2′ 2, whose length is proportional to the electric pressure at that point. In like manner other points are obtained, and the curved line through them will represent the variation in the electric pressure for all points of the revolution. At 90° the pressure is at a maximum, hence by using a pressure scale such that the length of the perpendicular 2′2 for 90° will measure the maximum pressure, the length of the perpendicular at any other point will represent the actual pressure at that point. The curve lies above the horizontal axis during the first half of the revolution and below it during the second half, which indicates that the current flows in one direction for a half revolution, and in the opposite direction during the remainder of the revolution.

[redacted]

and are changed into direct current by the action of the commutator. It was therefore necessary in that chapter, in presenting the basic principles of the dynamo, to explain the generation of alternating currents at length, and the graphic method of representing the alternating current cycle by the sine curve. In order to avoid unnecessary repetition, the reader

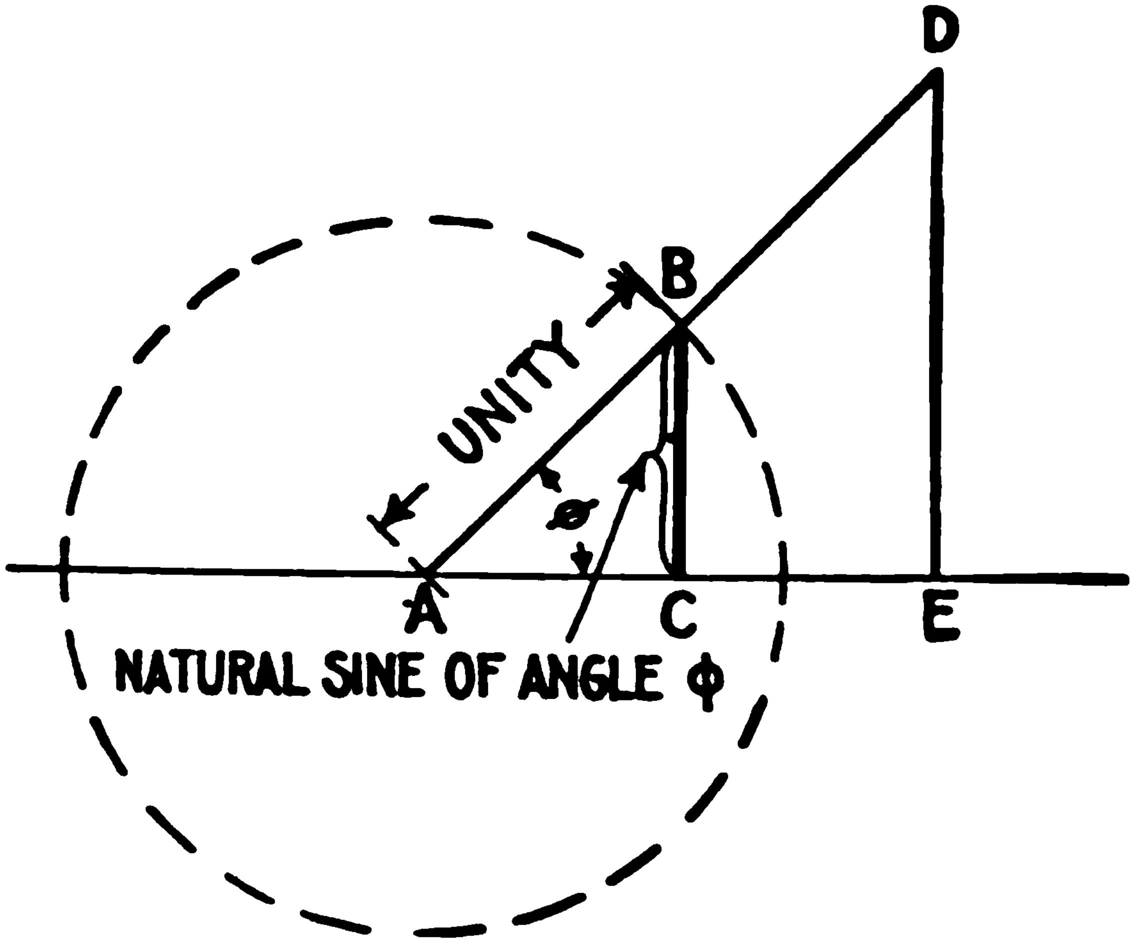


FIG. 1,219—Diagram illustrating the sine of an angle. In order to understand the sine curve, it is necessary to know the meaning of the sine of an angle. This is defined as *the ratio of the perpendicular let fall from any point in one side of the angle to the other side divided by the hypotenuse of the triangle thus formed.* For instance, in the diagram, let AD and AE be the two sides of the angle ϕ, and DE a perpendicular let fall from any point D of the side AD to the other side AE. Then, the sine of the angle (written $\sin\phi$) = DE ÷ AD. It is evident that if the perpendicular be let fall at a unit's distance from the apex A, as at B,

$$\sin\phi = \frac{BC}{AB} = \frac{BC}{1} = BC$$

This line BC is called the natural sine of the angle, and its values for different angles are given in the table on page 451.

should carefully review the above mentioned chapter before continuing further. The diagram fig. 168, showing the construction and application of the sine curve to the alternating current, is however for convenience here shown enlarged (fig. 1,218).

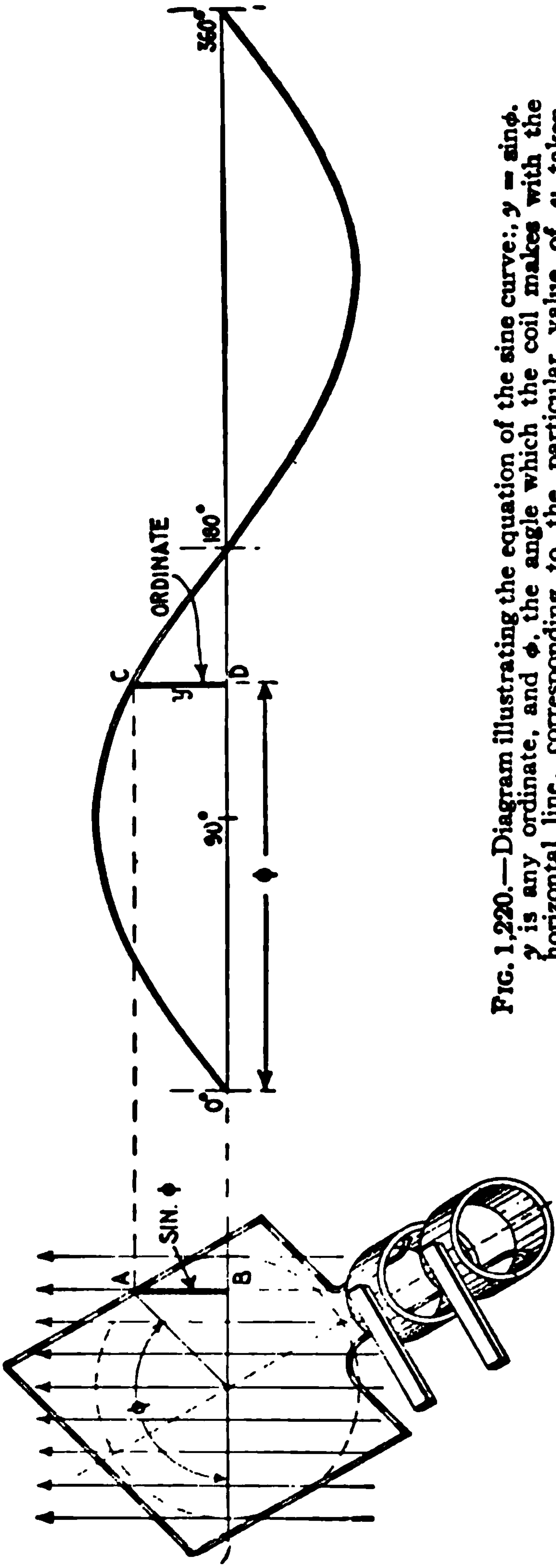


FIG. 1,220.—Diagram illustrating the equation of the sine curve: $y = \sin\phi$. y is any ordinate, and ϕ, the angle which the coil makes with the horizontal line, corresponding to the particular value of y taken.

In the diagram the various alternating current terms are graphically defined.

The alternating current, as has been explained, *rises from zero to a maximum, falls to zero, reverses its direction, attains a maximum in the new direction, and again returns to zero;* this comprises the *cycle.*

This series of changes can best be represented by a curve, whose abscissæ represent time, or degrees of armature rotation, and whose ordinates, either current or pressure. The curve usually chosen for this purpose is the sine curve, as shown in fig. 1,218, because it closely agrees with that given by most alternators.

The equation of the sine curve is

$$y = \sin\phi$$

in which y is any ordinate, and ϕ, the angle of the corresponding position of the coil in which the current is being generated as illustrated in fig. 1,220.

[redacted]

Ques. What is an alternation?

Ans. The changes which the current undergoes in rising from zero to maximum pressure and returning back to zero; that is, a single positive or negative "wave" or half period, as shown in fig. 1,221.

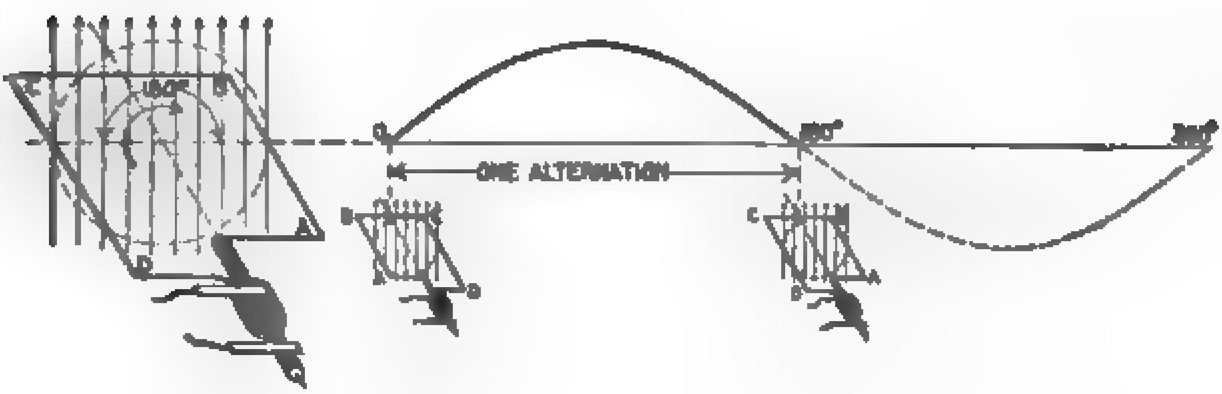


FIG. 1,221.—Diagram showing one *alternation* of the current in which the latter varies from zero to maximum and back to zero while the generating loop ABCD makes one half revolution.

Ques. What is the amplitude of the current?

Ans. The greatest value of the current strength attained during the cycle.

The foregoing definitions are also illustrated in fig. 1,218.

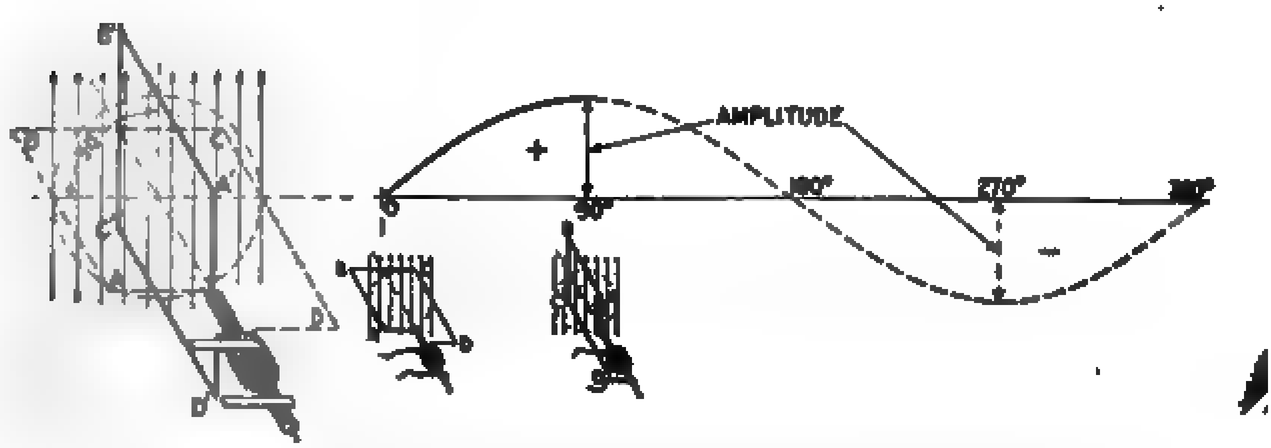


FIG. 1,222.—Diagram illustrating *amplitude* of the current. The current reaches its amplitude or maximum value in one quarter period from its point of zero value, as, for instance, while the generating loop moves from position ABCD to A'B'C'D'. At three-quarter revolution, the current reaches its maximum value in the opposite direction.

Ques. Define the term "period."

Ans. This is the time of one cycle of the alternating current.

Ques. What is periodicity?

Ans. A term sometimes used for *frequency*.

Frequency.—If a slowly varying alternating current be passed through an incandescent lamp, the filament will be seen to vary in brightness, following the change of current strength. If,

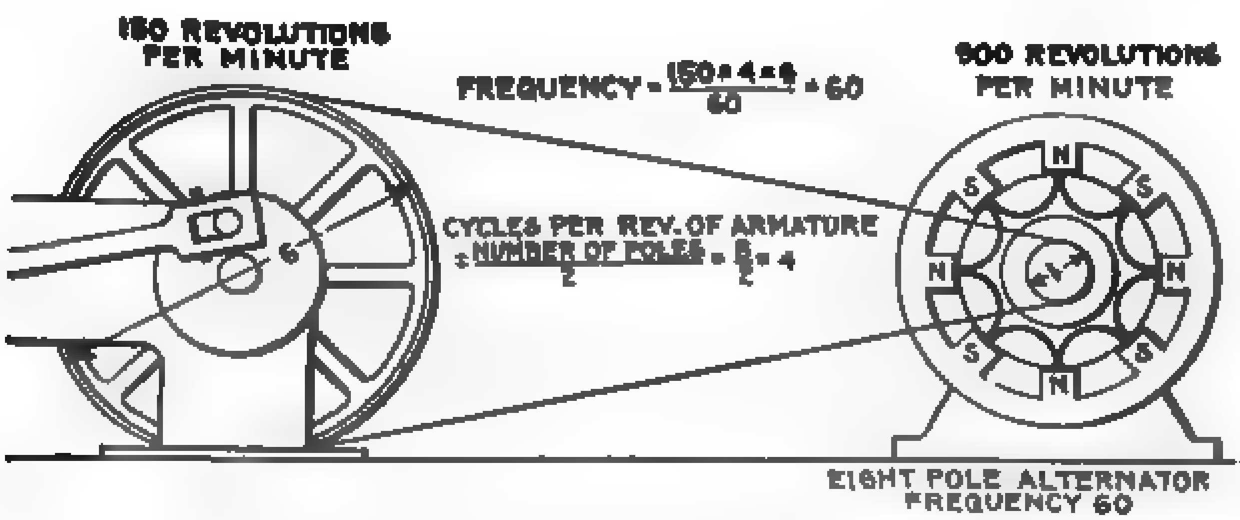


FIG. 1,223.—Diagram of alternator and engine, illustrating *frequency*. The frequency or *cycles per second* is equal to *the revolution of armature per second multipled by one-half the number of poles per phase*. In the figure the armature makes 6 revolutions to one of the engine; one-half the number of poles = 8 + 2 = 4, hence frequency = (150 × 4 × 6) + 60 = 60. The expression in the parenthesis gives the cycles per minute, and dividing by 60, the cycles per *second*.

however, the alternations take place more rapidly than about 50 to 60 per second, the eye cannot follow the variations and the lamp appears to burn steadily. Hence it is important to consider the rate at which the alternations take place, or as it is called, the *frequency*, which is defined as: *the number of cycles per second*.

In a two pole machine, the frequency is the same as the number of revolutions *per second*, but in multipolar machines, it is *greater in proportion* to the number of *pairs* of poles per phase.

Thus, in an 8 pole machine, there will be four cycles per revolution. If the speed be 900 revolutions per minute, the frequency is

$$\frac{8}{2} \times \frac{900}{60} = 60 \sim$$

The symbol $\sim$ is read "cycles per second."

Ques. What frequencies are used in commercial machines?

Ans. The two standard frequencies are 25 and 60 cycles.

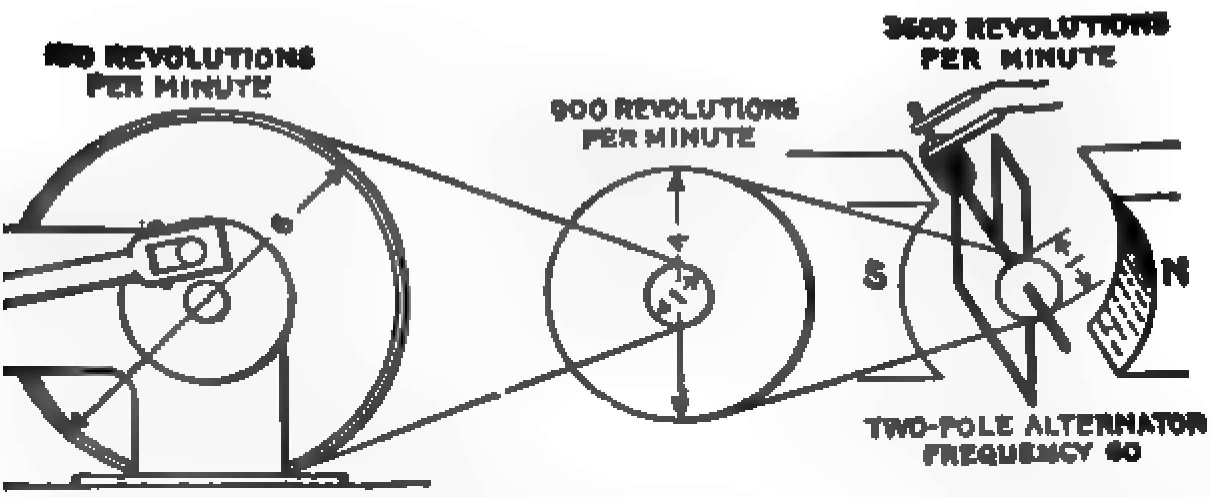


FIG. 1,224—Diagram answering the question: Why are alternators always built multipolar? They are made multipolar because it is desirable that the frequency be high. It is evident from the figure that to obtain high frequency would require too many revolutions of the armature of a bipolar machine for mechanical safety—especially in large alternators. Moreover a double reduction gear in most cases would be necessary, adding complication to the drive. Comparing the above illustration with fig. 1,223, shows plainly the reason for multipolar construction.

Ques. For what service are these frequencies adapted?

Ans. The 25 cycle frequency is used for conversion to direct current, for alternating current railways, and for machines of large size; the 60 cycle frequency is used for general distribution for lighting and power.

The frequency of 40 cycles, which once was introduced as a compromise between 25 and 60 has been found not desirable, as it is somewhat low for general distribution, and higher than desirable for conversion to *direct current*.

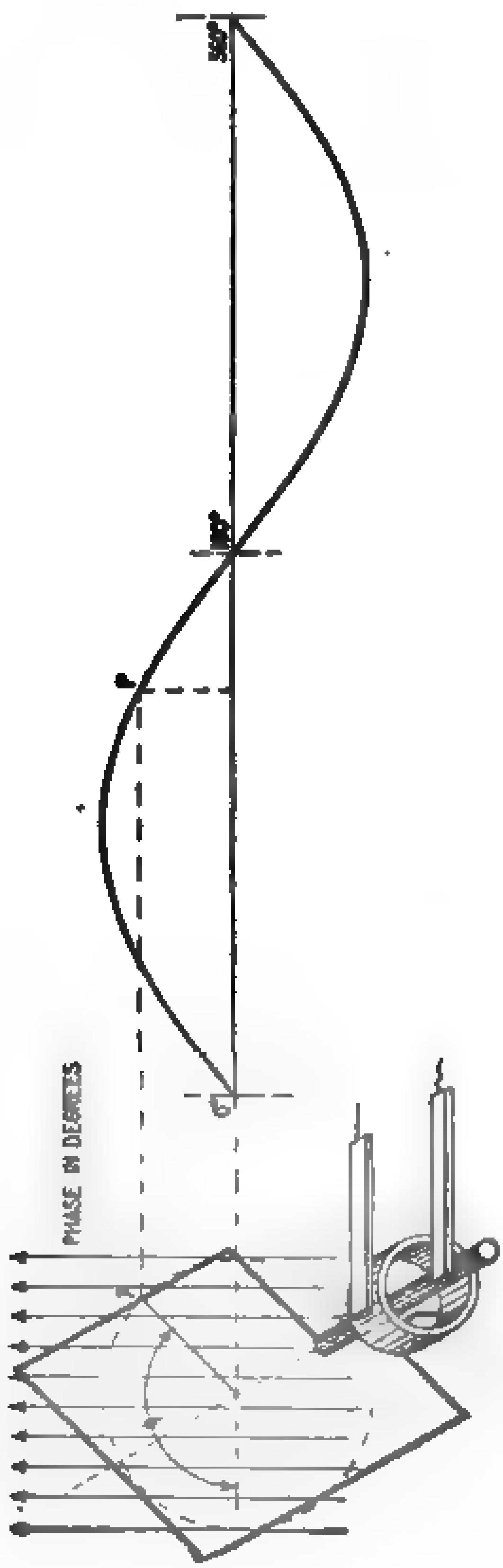


FIG. 1,225.—Diagram illustrating "phase." In wave, vibratory, and simple harmonic motion, phase may be defined as: *the portion of one complete vibration, measured either in angle or in time, that any moving point has executed.*

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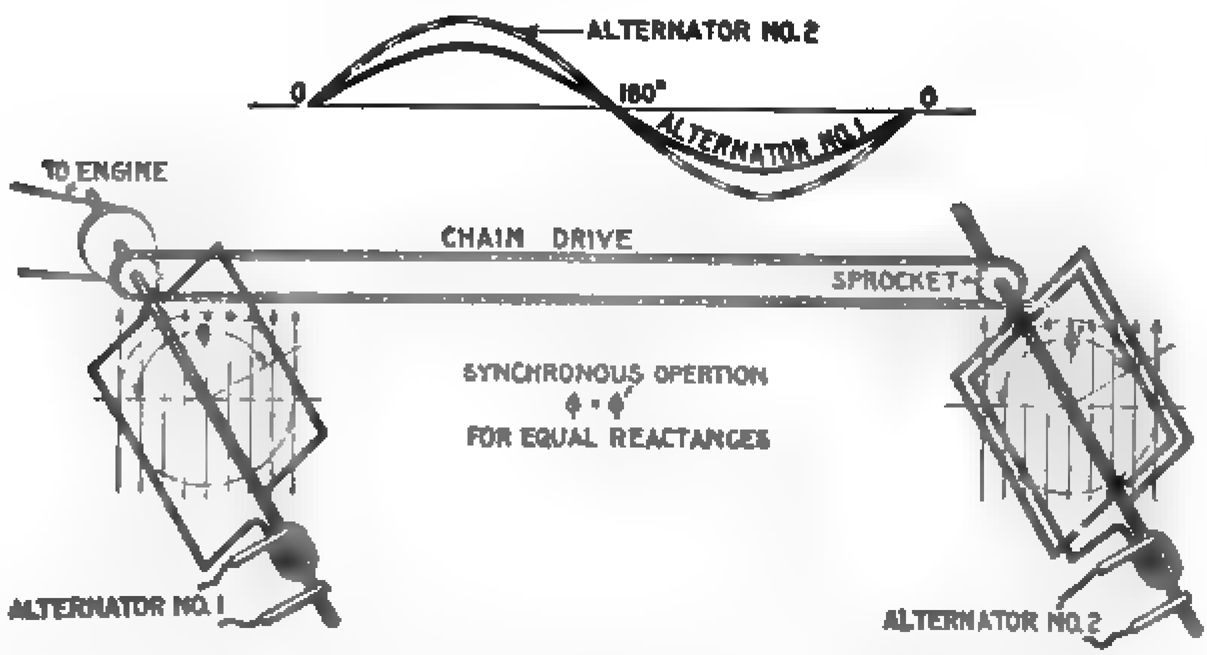
Ques. What is phase difference?

Ans. The angle between the phases of two or more alternating current quantities as measured in degrees.

Ques. What is phase displacement?

Ans. A change of phase of an alternating pressure or current.



FIGS. 1,226 and 1,227.—Diagram and sine curves illustrating *synchronism*. If two alternators, with coils in parallel planes, be made to rotate at the same speed by connecting them with chain drive or equivalent means, they will then be "in synchronism" that is, the alternating pressure or current in one will vary in step with that in the other. In other words, the cycles of one take place with the same frequency and at the same time as the cycles of the other as indicated by the curves, fig. 1,226. It should be noted that the maximum values are not necessarily the same but the maximum and zero values must occur at the same time in both machines, and the maximum value must be of the same sign. If the waves be distorted the maximum values may not occur simultaneously. See fig. 1,348

Synchronism.—This term may be defined as: *the simultaneous occurrence of any two events.* Thus two alternating currents or pressures are said to be "in synchronism" *when they have the same frequency and are in phase.*

Ques. What does the expression "in phase" mean?

Ans. Two alternating quantities are said to be in phase, when there is no *phase difference* between; that is when *the angle of phase difference equals zero.*

Thus the current is said to be in phase with the pressure when it neither lags nor leads, as in fig. 1,228.

A rotating cylinder, or the movement of an index or trailing arm is brought into synchronism with another rotating cylinder or another index or trailing arm, not only when the two are moving with exactly the same speed, but when in addition they *are simultaneously moving over similar portions of their respective paths.*

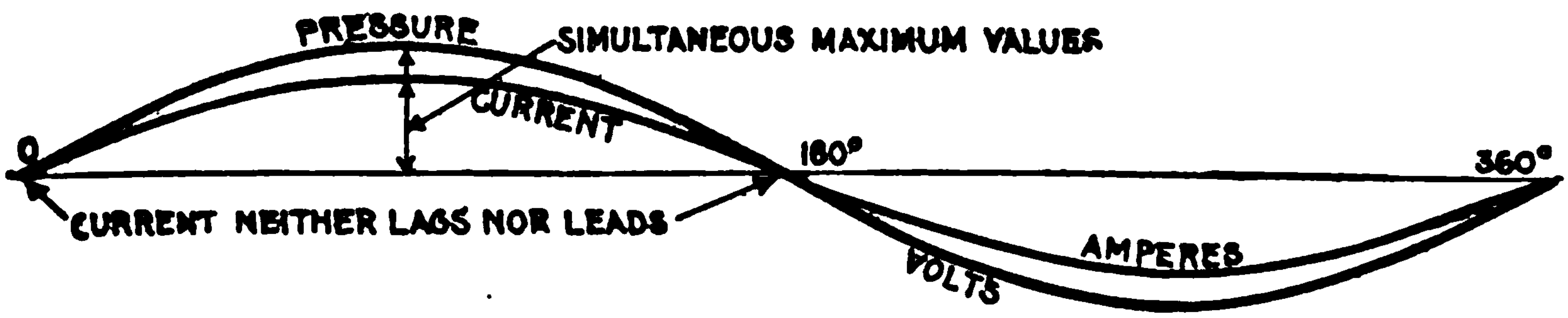


Fig. 1,228—Pressure and current curves illustrating the term "in phase." The current is said to be *in phase* with the pressure when it *neither* lags nor leads.

When there is phase difference, as between current and pressure, they are said to be " out of phase " the phase difference being measured as in fig. 1,229 by the angle ϕ.

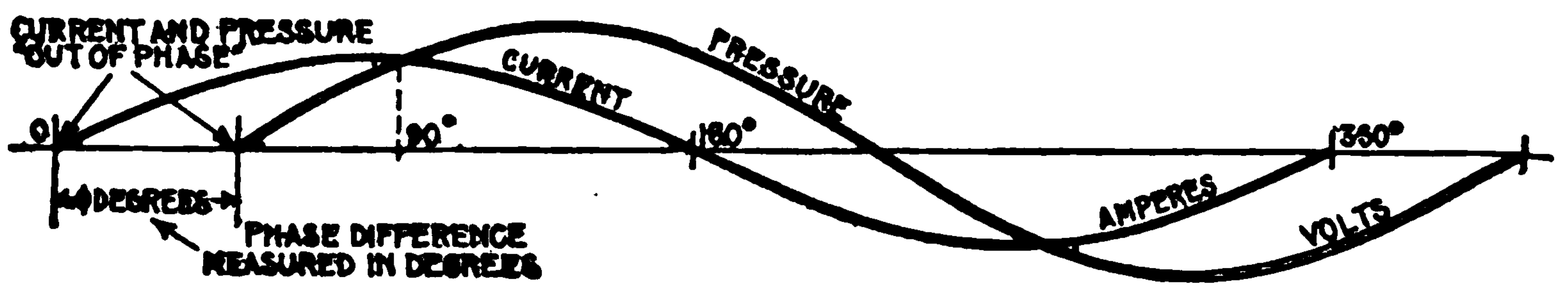


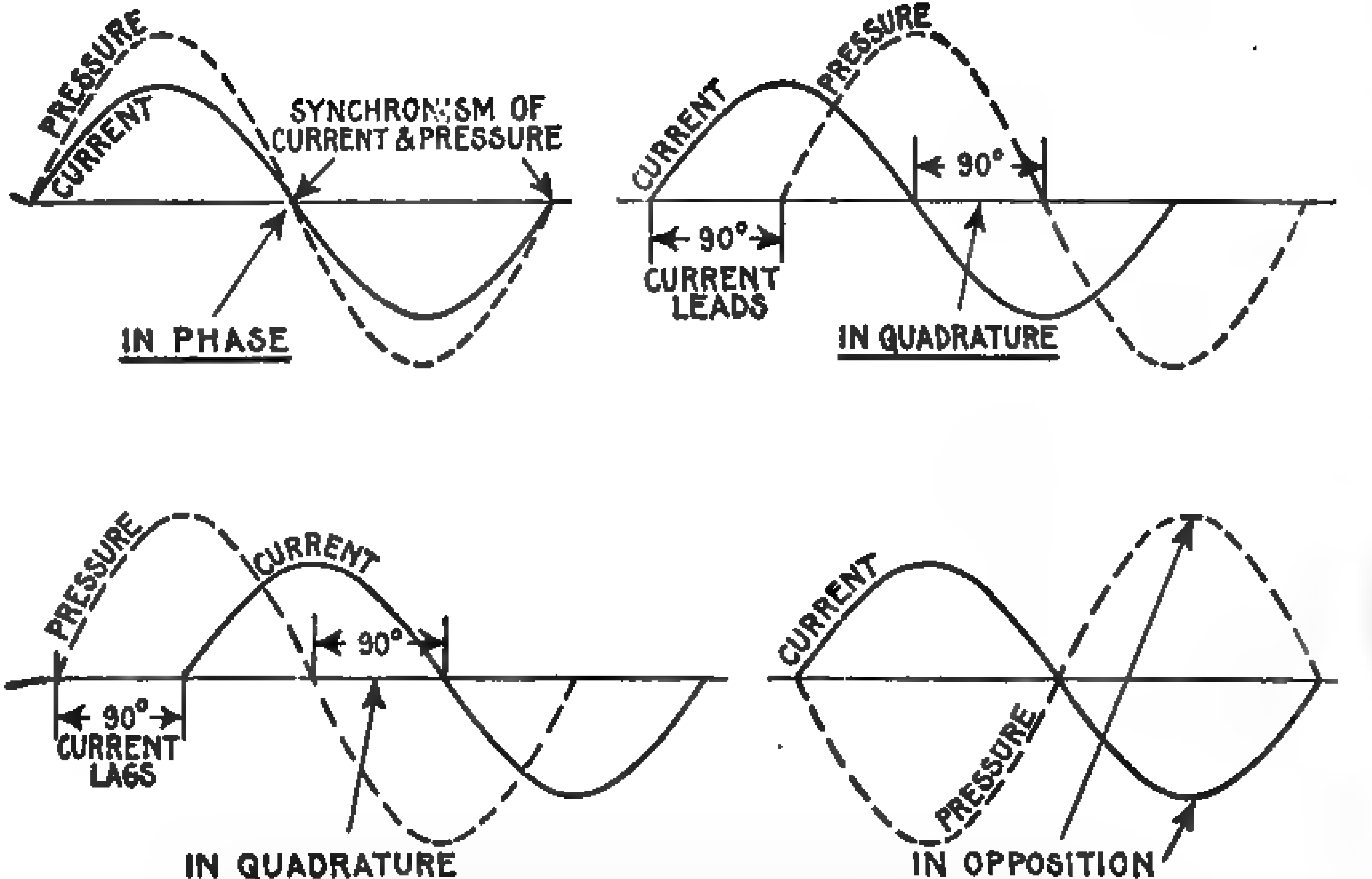
Fig. 1,229—Pressure and current curves illustrating the term "out of phase." The current is said to be *out of phase* with the pressure when it *either* lags or leads, that is when the current is not in synchronism with the pressure. In practice the current and pressure are nearly always out of phase.

When the phase difference is 90° as in fig. 1,231 or 1,232, the two alternating quantities are said to be *in quadrature;* when it is 180°, as in fig. 1,233, they are said to be *in opposition.*

When they are in quadrature, one is at a maximum when the other is at zero; when they are in opposition, one reaches a positive maximum when the other reaches a negative minimum, being at each instant opposite in sign.

Ques. What is a departure from synchronism called?

Ans. *Loss of synchronism.*



FIGS. 1,230 to 1,233.—Curves showing some phase, relations between current and pressure. Fig. 1,230, *synchronism of current* expressed by the term "in phase," meaning simultaneous zero values, and simultaneous maximum values of the 1,231, *in quadrature*, current *leading* 90°, fig 1,232 *in quadrature*, current lagging 90°; fig. 1,233, *in opposition*, the phase different between current and pressure is 180°

Maximum Volts and Amperes.—In the operation of an alternator, the pressure and strength of the current are continually rising, falling and reversing. During each cycle there are two points at which the pressure or current reaches its greatest value, being known as the *maximum value*. This maximum value is not used to any great extent, but it shows the maximum to which the pressure rises, and hence, the greatest strain to which the insulation of the alternator is subjected.

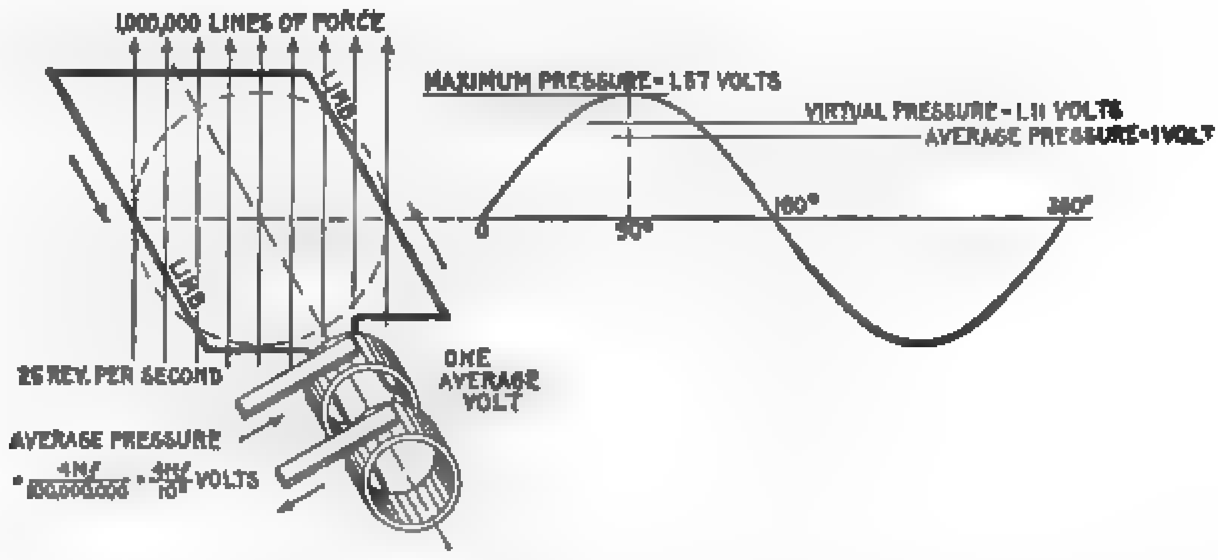


FIG. 1,234.—Elementary alternator developing one average volt. If the loop make one revolution per second, and the maximum number of lines of force embraced by the loop in the position shown (the zero position) be denoted by N, then each limb will cut 2N lines per second, because it cuts every line during the right sweep and again during the left sweep. Hence each limb develops an average pressure of 2N units (C.G.S. units) and as both limbs are connected in series, the total pressure is 4N units *per revolution*. Now, if the loop make f revolutions *per second* instead of only one, then f times as many lines will be cut *per second*, and the average pressure will be 4N f units. Since the C.G.S. unit of pressure is so extremely small, a much greater practical unit called the *volt* is used which is equal to 100,000,000, or 10^8 C.G.S. units is employed. Hence average voltage = $4Nf + 10^8$. The value of N in actual machines is very high, being several million lines of force. The illustration shows one set of conditions necessary to generate one average volt. The maximum pressure developed is 1 + .637 = 1.57 volts; virtual pressure = 1.57 × .707 = 1.11 volts.

Average Volts and Amperes.—Since the sine curve is used to represent the alternating current, the *average value* may be defined as: *the average of all the ordinates of the curve for one-half of a cycle.*

[redacted]

Ques. Of what use is the average value?

Ans. It is used in some calculations but, like the maximum value, not very often. The relation between the average and virtual value is of importance as it gives the form factor.

Virtual Volts and Amperes.—The virtual* value of an alternating pressure or current *is equivalent to that of a direct pressure or current which would produce the same effect;* those

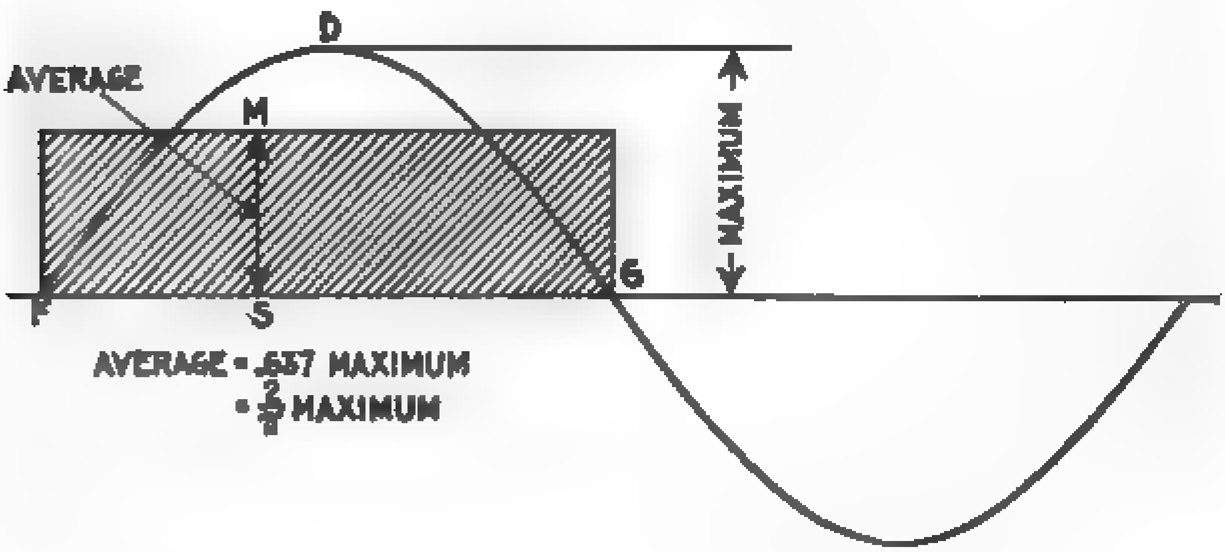


FIG. 1,235.—Maximum and average values of the sine curve. The average value of the sine curve is represented by an ordinate MS of such length that when multiplied by the base line FG, will give a rectangle MPSG whose area is equal to that included between the curve and base line FDGS.

effects of the pressure and current are taken which are not affected by rapid changes in direction and strength,—in the case of pressure, the reading of an electrostatic voltmeter, and in the case of current, the heating effect.

*NOTE.—"I adhere to the term *virtual*, as it was in use before the term *efficace* which was recommended in 1889 by the Paris Congress to denote the *square root of mean square* value. The corresponding English adjective is *efficacious;* but some engineers mistranslate it with the word *effective*. I adhere to the term *virtual* mainly because the adjective *effective* is required in its usual meaning in kinematics to represent the resolved part of a force which acts obliquely to the line of motion, the effective force being the whole force multiplied by the cosine of the angle at which it acts with respect to the direction of motion. Some authors use the expression 'R. M. S. value' (meaning 'root mean square') to denote the virtual or quadratic mean value."—*S. P. Thompson.*

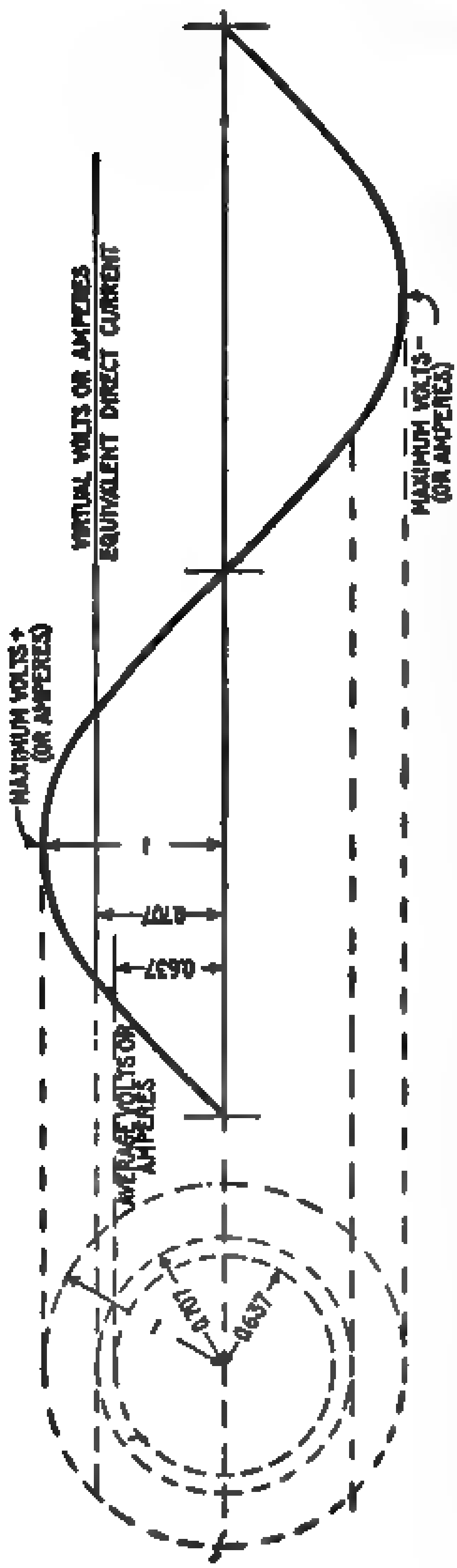


FIG. 1,236.—Diagram illustrating "virtual" volts and amperes. The word *virtual* is defined as: *Being in essence or effect, not in fact; not actual, but equivalent, so far as effect is concerned.* As applied to the alternating current, it denotes an imaginary direct current of such value as will produce an effect equivalent to that of the alternating current. Thus, a *virtual pressure* of 1,000 volts is one that would produce the same deflection in an electrostatic voltmeter as a direct pressure of 1,000 volts; a *virtual current* of 10 amperes is that current which would produce the same heating effect as a direct current of 10 amperes. Both pressure and current vary continually above and below the virtual values in alternating current circuits. Distinction should be made between the virtual and "effective" values of an alternating current. See fig. 1,237. The word *effective* is commonly used erroneously for *virtual*. See note page 1,011.

The attraction (or repulsion) in electrostatic voltmeters is proportional to the square of the volts.

The readings which these instruments give, if first calibrated by using steady currents, are not true means, but are ***the square roots of the means of the squares.***

Now the mean of the squares of the sine (taken over either one quadrant or a whole circle) is $\frac{1}{2}$; hence the ***square root of mean square*** value of the sine functions is obtained by multiplying their maximum value by $1 \div \sqrt{2}$, or by 0.707.

The arithmetical mean of the values of the sine, however, is 0.637. Hence an alternating current, if it obey the sine law, will produce a heating effect greater than that of a steady current of the same average strength, by the ratio of 0.707 to 0.637; that is, about 1.11 times greater.

If a Cardew voltmeter be placed on an alternating circuit in which the volts are oscillating between maxima of +100 and −100 volts, it will read 70.7 volts, though the arithmetical mean is really only 63.7; and 70.7 steady volts would be required to produce an equal reading.

The matter may be looked at in a different way. If an alternating current is to produce in a given wire the same amount of effect as a continuous current of 100 amperes, since the alternating current goes down to zero twice in each period, it is clear that it must at some point in the period rise to a maximum greater than 100 amperes. How much greater must the maximum be? The answer is that, if it undulate up and down with a pure wave form, its maximum must be $\sqrt{2}$ times as great as the virtual mean, or conversely the virtual amperes will be equal to the maximum divided by $\sqrt{2}$. In fact, to produce equal effect, the equivalent direct current will be a kind of mean between the

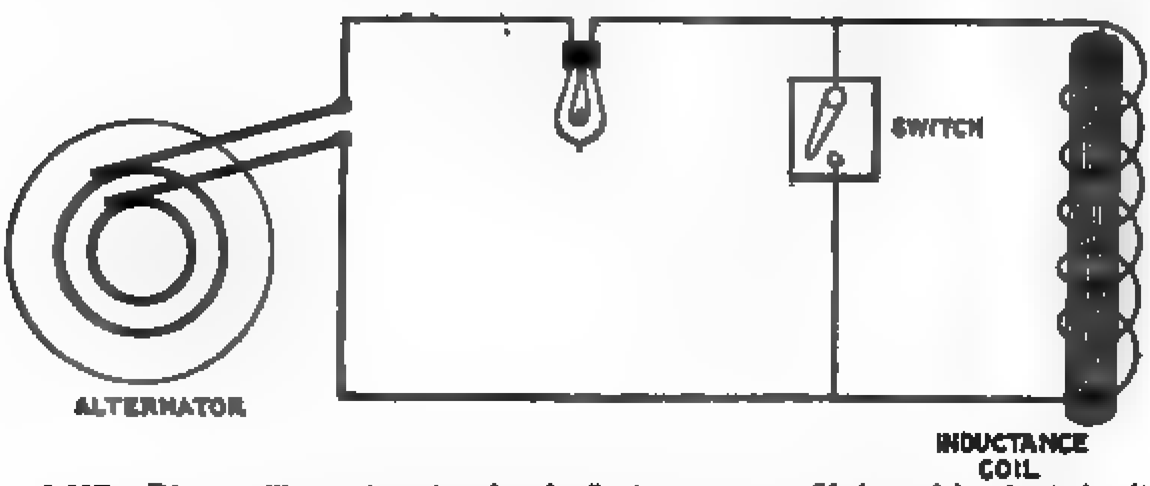


FIG. 1,237.—Diagram illustrating *virtual* and *effective* pressure. If the coil be short circuited by the switch and a constant virtual pressure be impressed on the circuit, the whole of the impressed pressure will be effective in causing current to flow around the circuit. In this case the virtual and effective pressures will be equal. If the coil be switched into circuit, the reverse pressure due to self induction will oppose the virtual pressure; hence, the effective pressure (which is the difference between the virtual and reverse pressures) will be reduced, the virtual or impressed pressure remaining constant all the time. A virtual current *is that indicated by an ammeter regardless of the phase relation between current and pressure.* An effective current *is that indicated by an ammeter when the current is in phase with the pressure.* In practice, the current is hardly ever in phase with the pressure, usually lagging, though sometimes leading in phase. Now the greater this phase difference, either way, the less is the power of a given virtual current to do work. With respect to this feature, effective current may be defined as: *that proportion of a given virtual current which can do useful work.* If there be no phase difference, then effective current is equal to virtual current.

maximum and the zero value of the alternating current; but it must not be the arithmetical mean, nor the geometrical mean, nor the harmonic mean, but the *quadratic* mean; that is, it will be the *square root of the mean of the squares* of all the instantaneous values between zero and maximum.

Effective Volts and Amperes.—Virtual pressure, although already explained, may be further defined as the pressure *impressed* on a circuit. Now, in nearly all circuits the impressed

or virtual pressure meets with an opposing pressure due to inductance and hence the *effective* pressure is something less than the virtual, being defined as *that pressure which is available for driving electricity around the circuit, or for doing work.* The difference between virtual and effective pressure is illustrated in fig. 1,237.

Ques. Does a given alternating voltage affect the insulation of the circuit differently than a direct pressure of the same value?

Ans. It puts more strain on the insulation in the same proportion as the maximum pressure exceeds the virtual pressure.

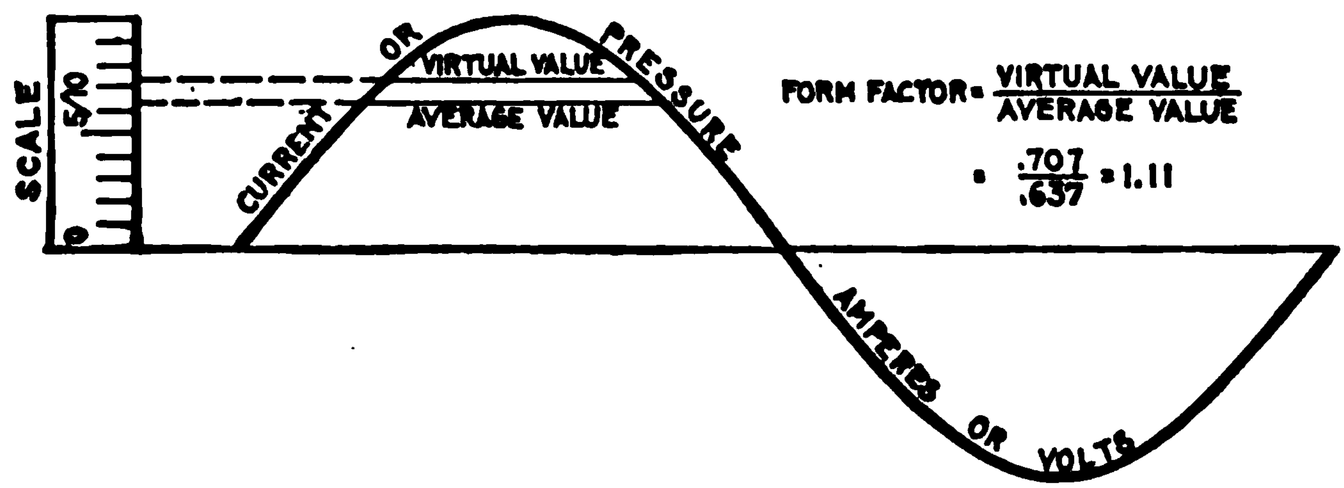


Fig. 1,238.—Current or pressure curve illustrating *form factor*. It is simply ***the virtual value divided by the average value.*** For a sine wave the virtual value is $\frac{1}{\sqrt{2}}$ times the maximum, and the average is $\frac{2}{\pi}$ times the maximum, so that the form factor is $\frac{\pi}{2\sqrt{2}}$=or 1.11. The induction wave which generates an alternating pressure wave has a maximum value proportional to the area, that is, to the average value of the pressure wave. Hence the induction values corresponding to two pressure waves whose virtual values are equal, will be inversely proportional to their form factors. This is illustrated by the fact that a *peaked* wave causes less hysteresis loss in a transformer core than a flat topped wave, owing to the higher form factor of the peaked wave. See wave forms, figs. 1,245 to 1,248.

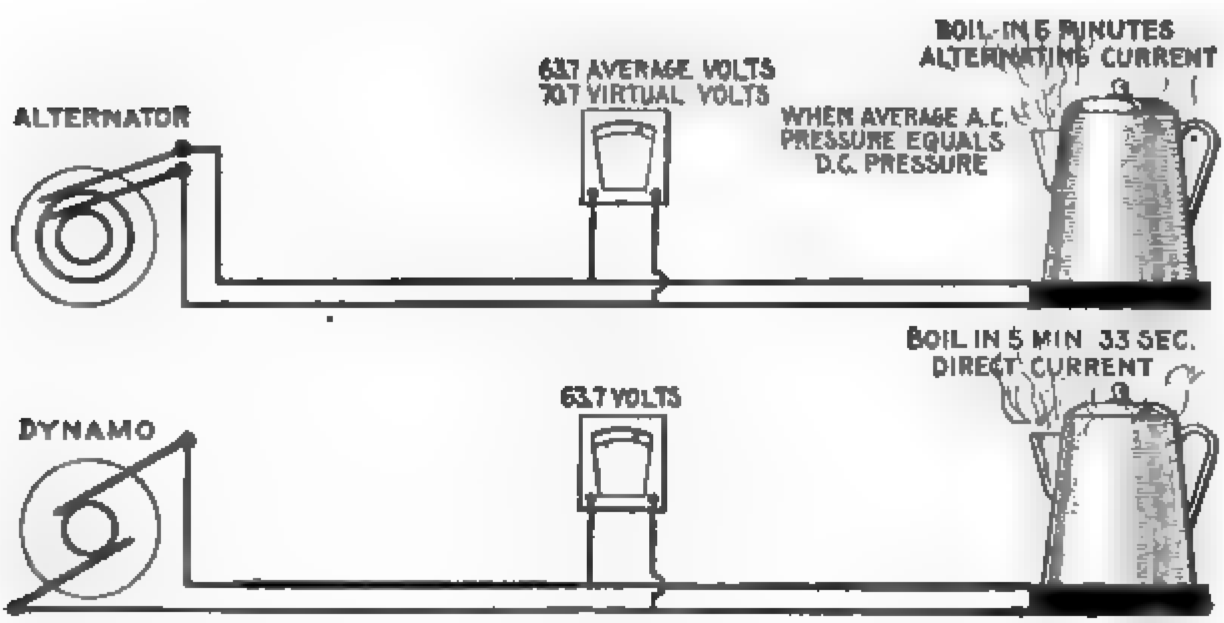
Form Factor.—This term was introduced by Fleming, and denotes the ratio of the virtual value of an alternating wave to the average value. That is

$$\text{form factor} = \frac{\text{virtual value}}{\text{average value}} = \frac{.707}{.637} = 1.11$$

Ques. What does this indicate?

Ans. It gives the relative heating effects of alternating and direct currents, as illustrated in figs. 1,239 and 1,240.

That is, the alternating current will have about 11 per cent. more heating power than the direct current which is of the same *average* strength. If an alternating current voltmeter be placed upon a circuit in which the volts range from +100 to −100, it will read 70.7 volts, although the arithmetical average, irrespective of + or − sign, is only 63.7 volts. If the voltmeter be connected to a direct current circuit, the pressure necessary to give the same reading would be 70.7 volts.

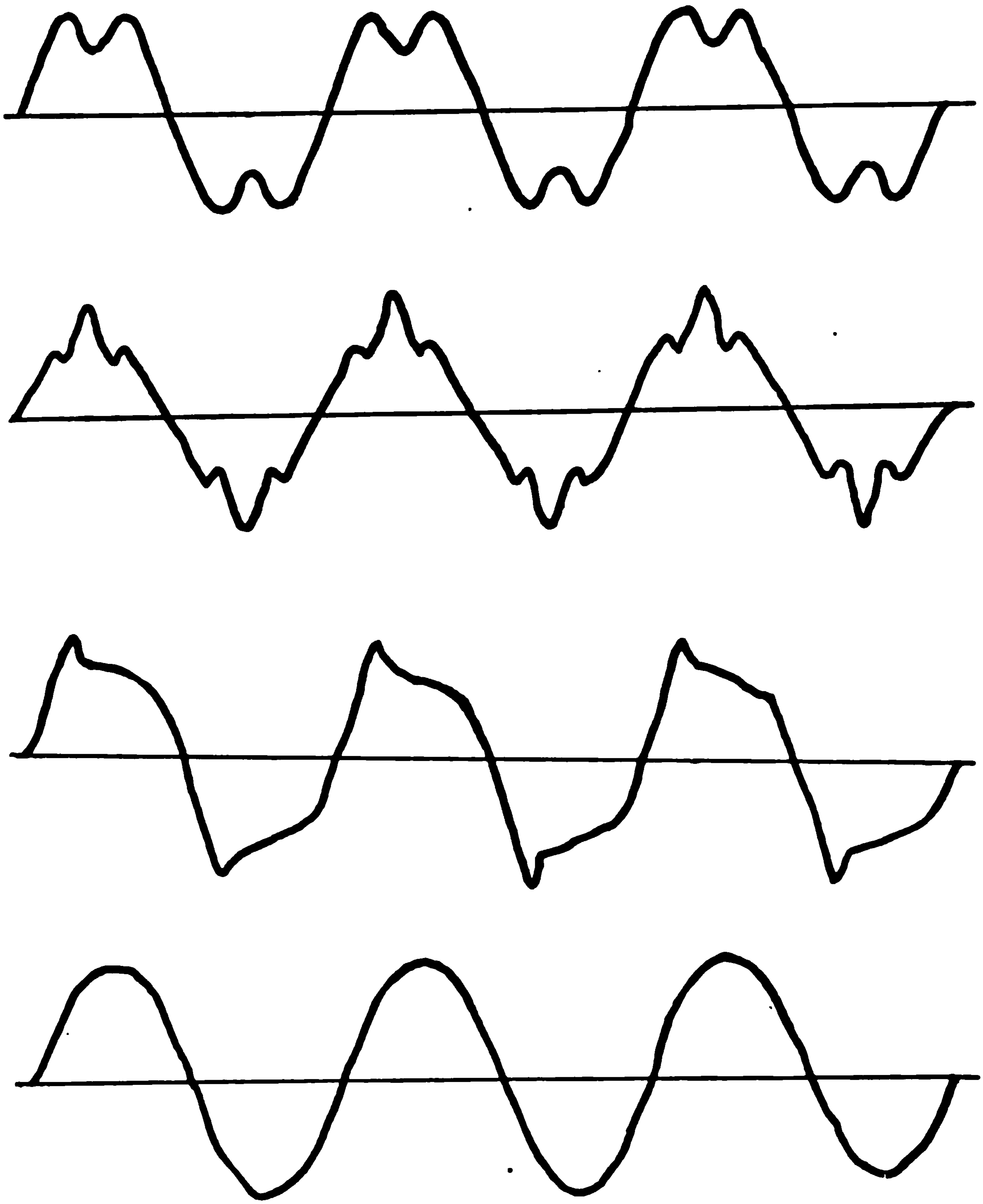


FIGS. 1,239 and 1,240.—Relative heating effects of alternating and direct currents. If it take say five minutes to produce a certain heating effect with alternating current at say 63.7 *average* volts, it will take 33 seconds longer with direct current at the same pressure, that is, the alternating current has about 11 per cent. more heating power than the direct current of the same *average* pressure. The reader should be careful not to get a wrong conception of the above; it does not mean that there is a saving by using alternating current. When both voltmeters read the same, that is, when the *virtual* pressure of the alternating current is the same as the direct current pressure, the heating effect is of course the same.

Ques. What is the relation between the shape of the wave curve and the form factor?

Ans. The more peaked the wave, the greater the value of its form factor.

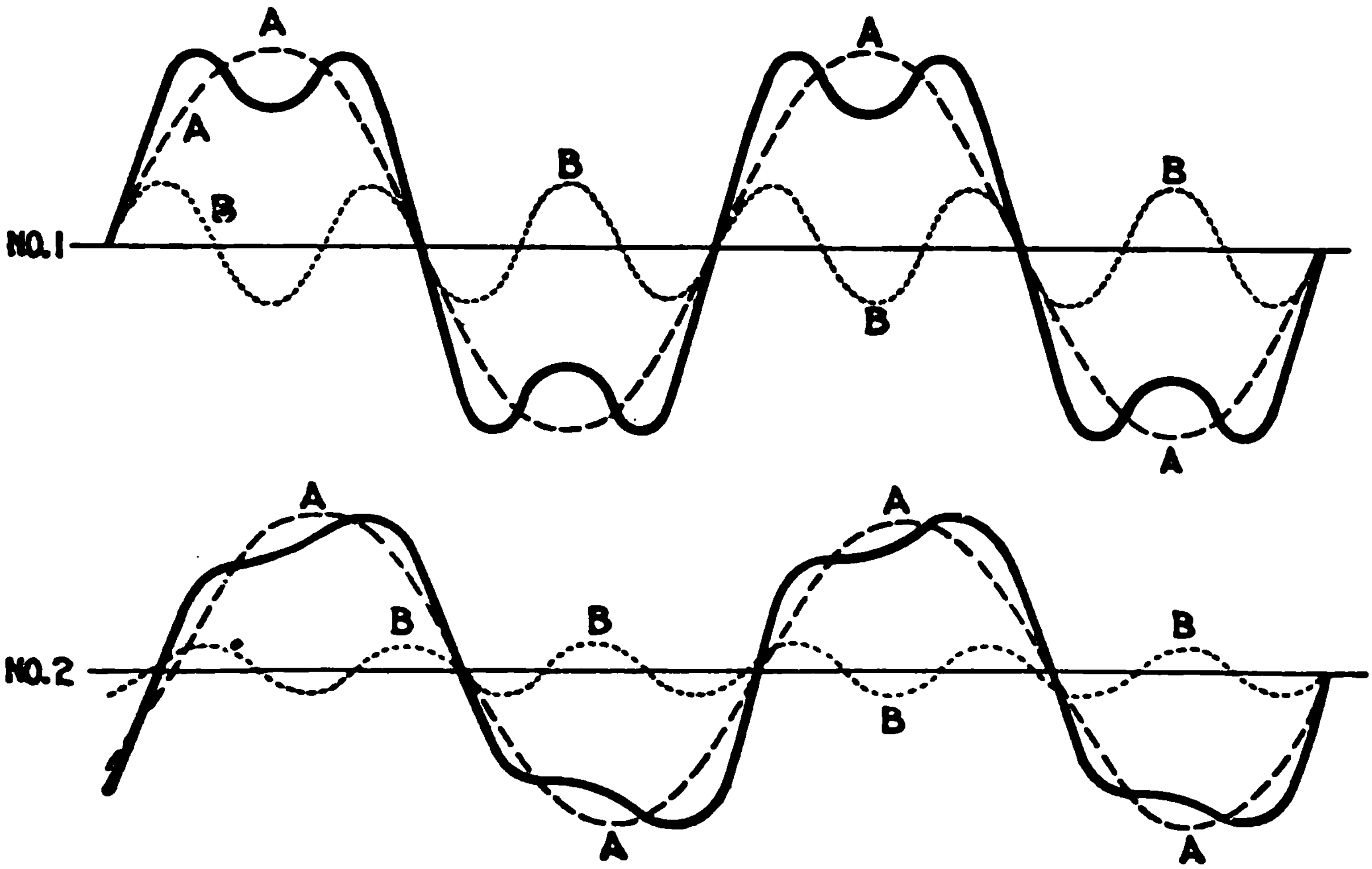
A form factor of units would correspond to a rectangular wave; this is the least possible value of the form factor, and one which is not realised in commercial *machines*.



FIGS. 1,241 to 1,244.—Various forms of pressure or current waves. Figs. 1,241 to 1,243 show the general shape of the waves produced by some alternators used largely for lighting work and having toothed armatures. The effect of the slots and shape of pole pieces is here very marked. Fig. 1,244 shows a wave characteristic of large alternators designed *for power transmission and having* multi-slot or distributed windings.

Wave Form.—There is always more or less irregularity in the shape of the current waves as met in practice, depending upon the construction of the alternator.

The ideal wave curve is the so called *true sine wave*, and is obtained with a rate of cutting of lines of force, by the armature coils, equivalent to the swing of a pendulum, which increases



FIGS. 1,245 and 1,246.—Resolution of complex curves into sine curves. The heavy curve can be resolved into the simpler curves A and B shown in No. 1, the component curves A and B have in the ratio of three to one; that is, curve B has three times as many periods per second as curve A. All the curves, however, cross the zero line at the same time, and the resultant curve, though curiously unlike either of them, has a certain symmetry. In No. 2 the component curves, besides having periods in the ratio of three to one, cross the zero line at different points. The resultant curve produced is still less similar to its components, and is curiously and unsymmetrically humped. At first sight it is difficult to believe that such a curious curve could be resolved into two such simple and symmetrical ones. In both figures the component curves are sine curves, and as the curves for sine and cosine functions are exactly similar in form, the simplest supposition that can be made for the variation of pressure or of current is that both follow a *sine law*.

in speed from the end to the middle of the swing, decreasing at the same rate after passing the center. This swing is expressed in physics, as "simple harmonic motion."

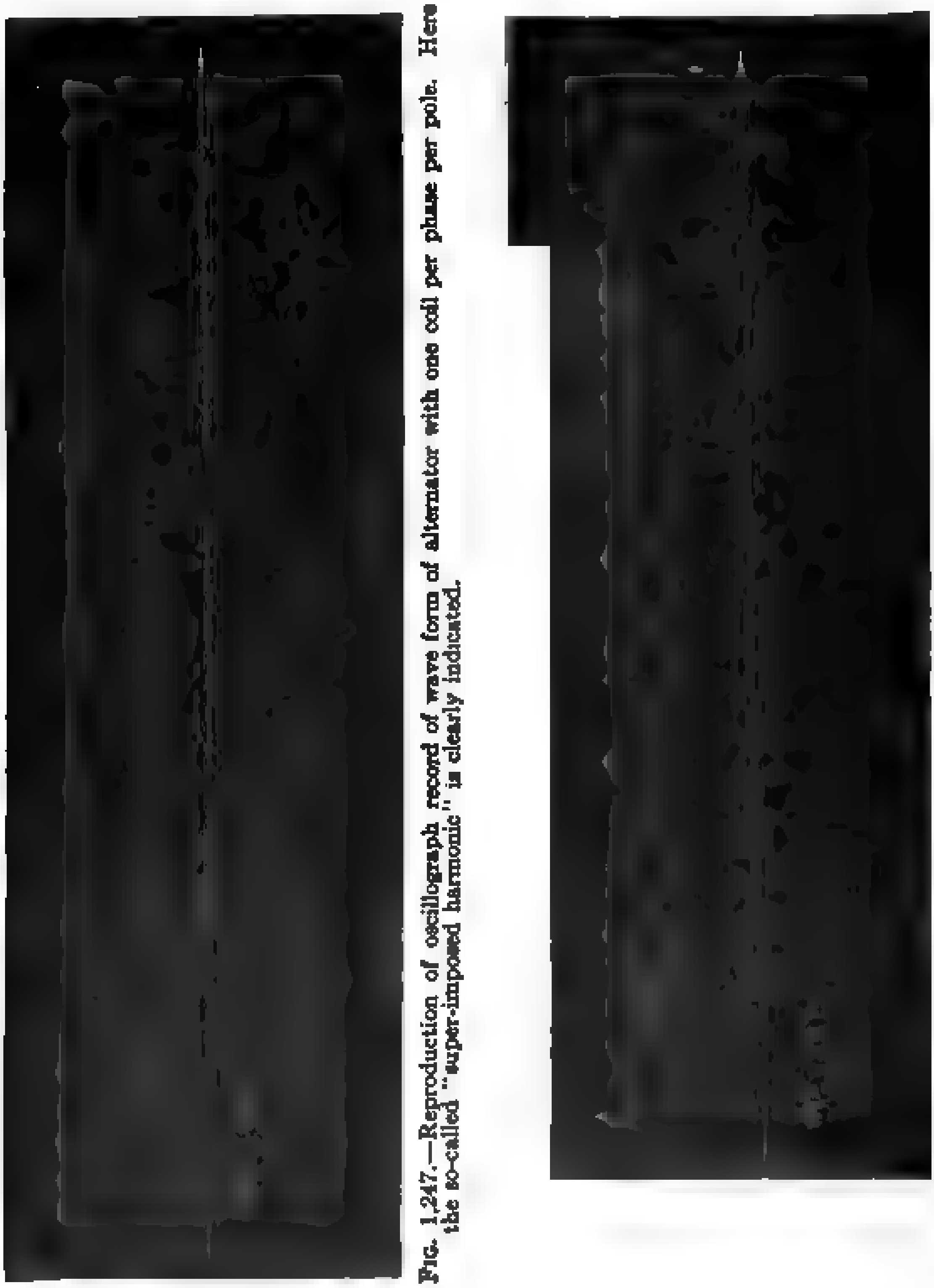


FIG. 1,247.—Reproduction of oscillograph record of wave form of alternator with one coil per phase per pole. Here the so-called "super-imposed harmonic" is clearly indicated.

The losses in all secondary apparatus are slightly lower with the so called *peaked* form of wave. For the same virtual voltage, however, the top of the peak will be much higher, thereby submitting the insulation to that much greater strain. By reason of the fact that the losses are less under such wave forms, many manufacturers in submitting performance data on transformers recite that the figures are for sine wave conditions, stating further that if the transformers are to be operated in a circuit more peaked than the sine wave, the losses will be less than shown.

The slight saving in the losses of secondary apparatus, obtained with a peaked wave, by no means compensates for the increased insulation strains and an alternator having a true sine wave is preferred.

Ques. What determines the form of the wave?

Ans. 1. The number of coils per phase per pole, 2, shape of pole faces, 3, eddy currents in the pole pieces, and 4, the air gap.

Ques. What are the requirements for proper rate of cutting of the lines of force?

Ans. It is necessary to have, as a minimum, two coils per phase per pole in three phase work.

Ques. What is the effect of only one coil per phase per pole?

Ans. The wave form will be distorted as shown in fig. 1,247.

Ques. What is the least number of coils per phase per pole that should be used for two and three phase alternators?

Ans. For three phase, two coils, and for two phase, three coils, per phase per pole.

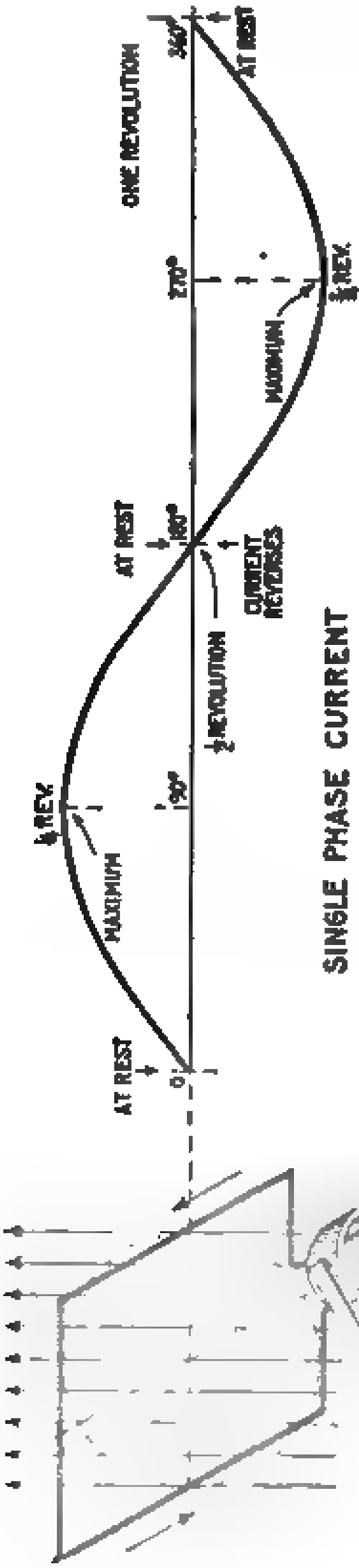
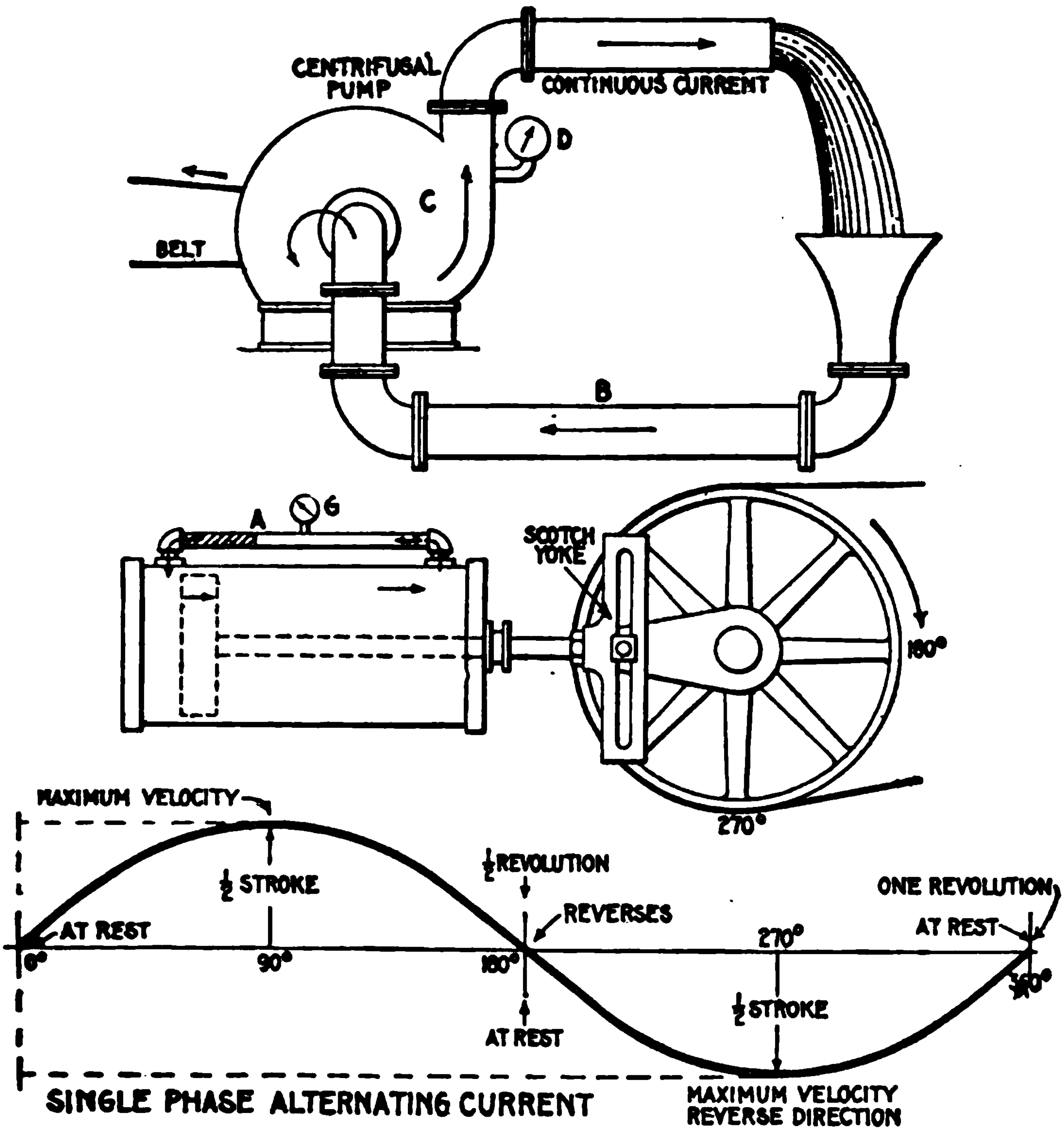


FIG. 1,249.—Elementary one loop alternator and sine curve illustrating single phase alternating current. There are three points during the revolution at which there is no current; at 0° the position shown, 180°, and 360°; in other words, at the beginning, middle point and end of the cycle. The current reaches a maximum at 90°, reverses at 180°, and reaches a maximum in the reverse direction at 270°.

Single or Monophase Current.—This kind of alternating current is generated by an alternator having a single winding on its armature. Two wires, a lead and return, are used as in direct current.

An elementary diagram showing the working principles is illustrated in fig. 1,249, a similar hydraulic cycle being shown in figs. 1,250 to 1,252.

Two Phase Current.—In most cases two phase current actually consists of two distinct single phase currents flowing in separate circuits. There is often no electrical connection between them; they are of equal period and equal amplitude, but differ in phase by one quarter of a period. With this phase relation one of them will be at a maximum when the other is at zero. Two phase current is illustrated



FIGS. 1,250 to 1,252.—Hydraulic analogy illustrating the difference between *direct* (continuous) and *alternating* current. In fig. 1,250 a centrifugal pump C forces water to the upper pipe, from which it falls by gravity to the lower pipe B and re-enters the pump. The current is continuous, always flowing in one direction, that is, it does not reverse its direction. Similarly a direct electric current is constant in direction (does not reverse), though not necessarily constant in value. A direct current, constant in both value and direction as a result of constant pressure, is called "continuous" current. Similarly in the figure the flow is constant, and a gauge D placed at any point will register a constant pressure, hence the current may be called, in the electrical sense, "continuous." The conditions in fig. 1,251 are quite different. The illustration represents a double acting cylinder with the ends connected by a pipe A, and the piston driven by crank and Scotch yoke as shown. In operation, if the cylinder and pipe be full of water, a current of water will begin to flow through the pipe in the direction indicated as the piston begins its stroke, increasing to maximum velocity at one-quarter revolution of the crank, decreasing and coming to rest at one-half revolution, then reversing and reaching maximum velocity in the reverse direction at three-quarter revolution, and coming to rest again at the end of the return stroke. A pressure gauge at G will register a pressure which varies with the current. Since the *alternating electric current* undergoes similar changes, the sine curve will *apply equally as well to the pump cycle* as to the alternating current cycle.

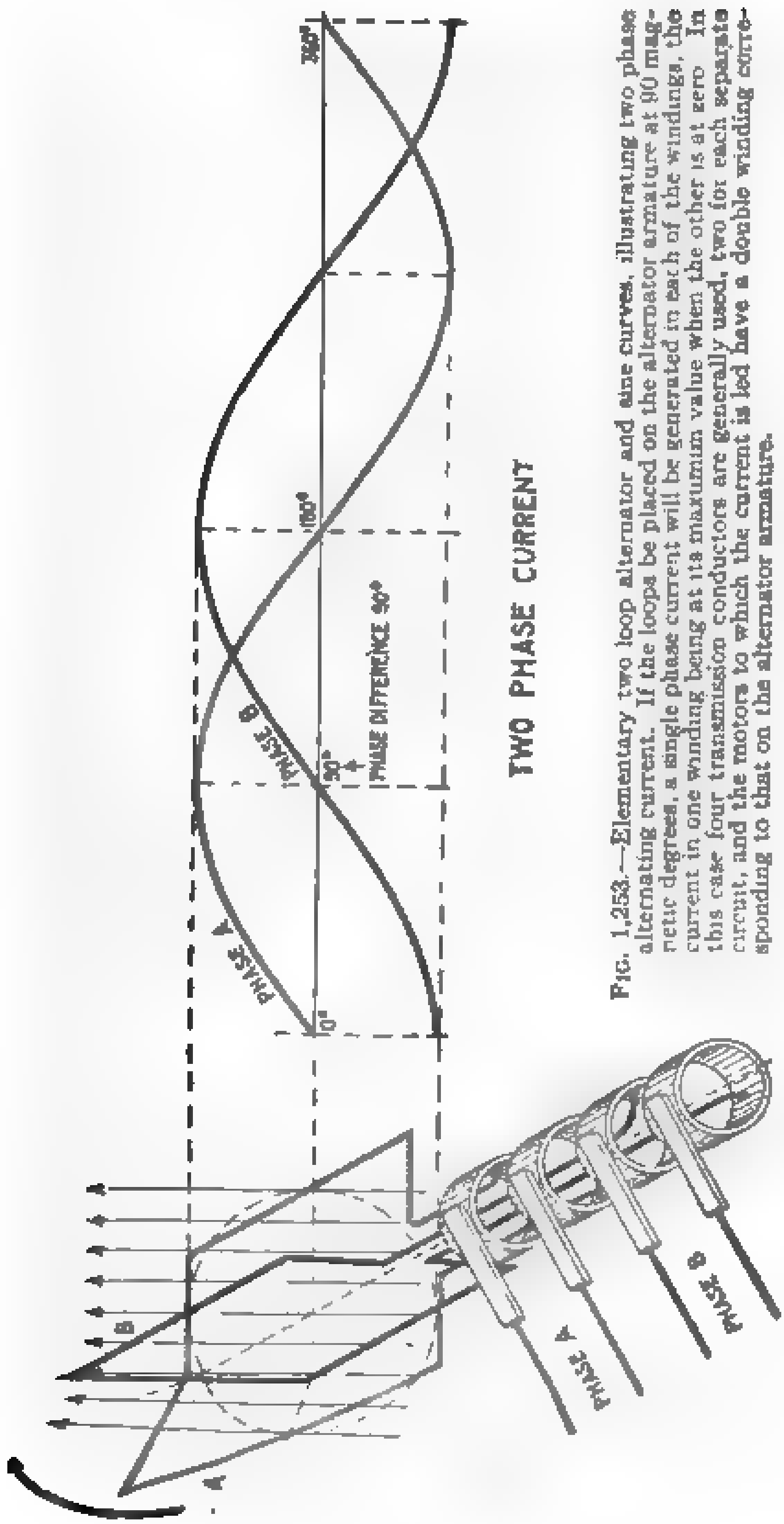


FIG. 1,253.—Elementary two loop alternator and sine curves, illustrating two phase alternating current. If the loops be placed on the alternator armature at 90 magnetic degrees, a single phase current will be generated in each of the windings, the current in one winding being at its maximum value when the other is at zero. In this case four transmission conductors are generally used, two for each separate circuit, and the motors to which the current is led have a double winding corresponding to that on the alternator armature.

by sine curves in fig. 1,253, and by hydraulic analogy in figs. 1,254 and 1,255.

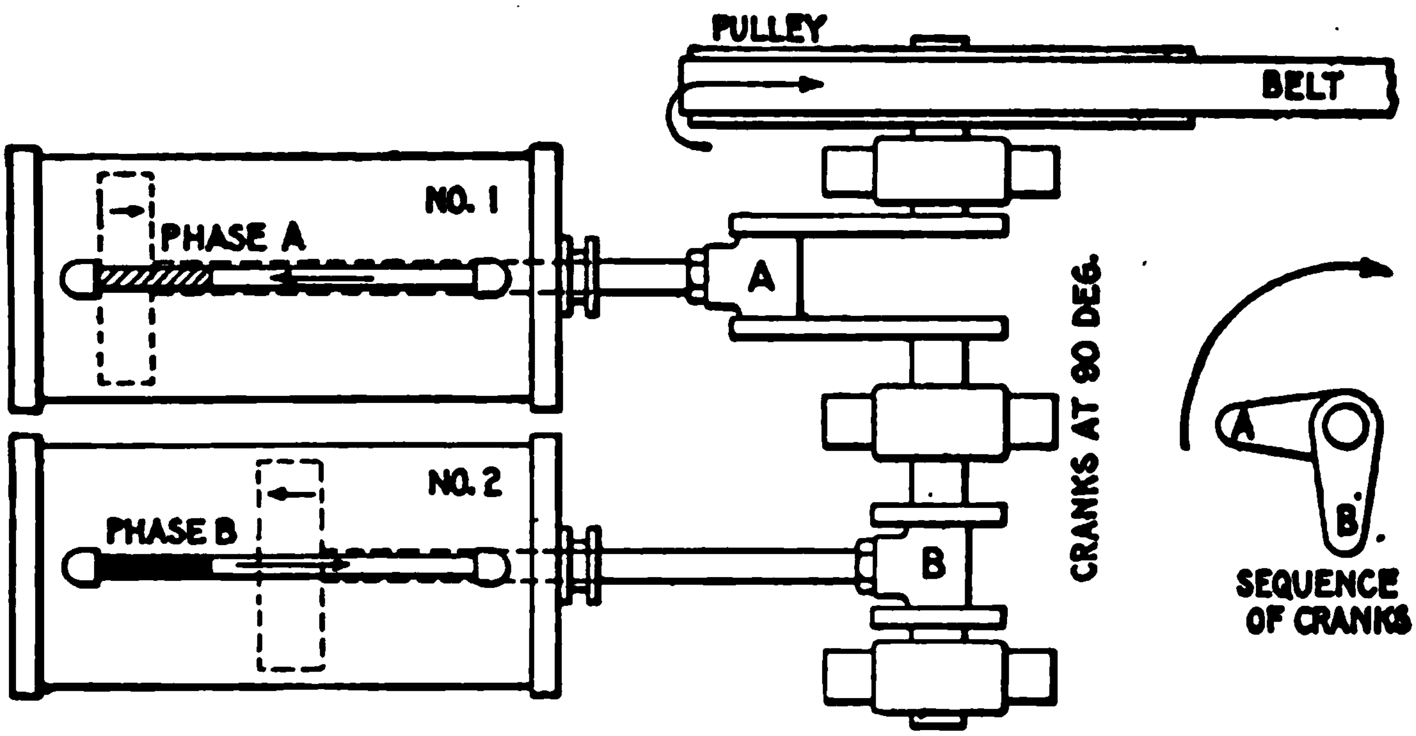
If two identical simple alternators have their armature shafts coupled in such a manner, that when a given armature coil on one is directly under a field pole, the corresponding coil on the other is midway between two poles of its field, the two currents generated will differ in phase by a half alternation, and will be two phase current.

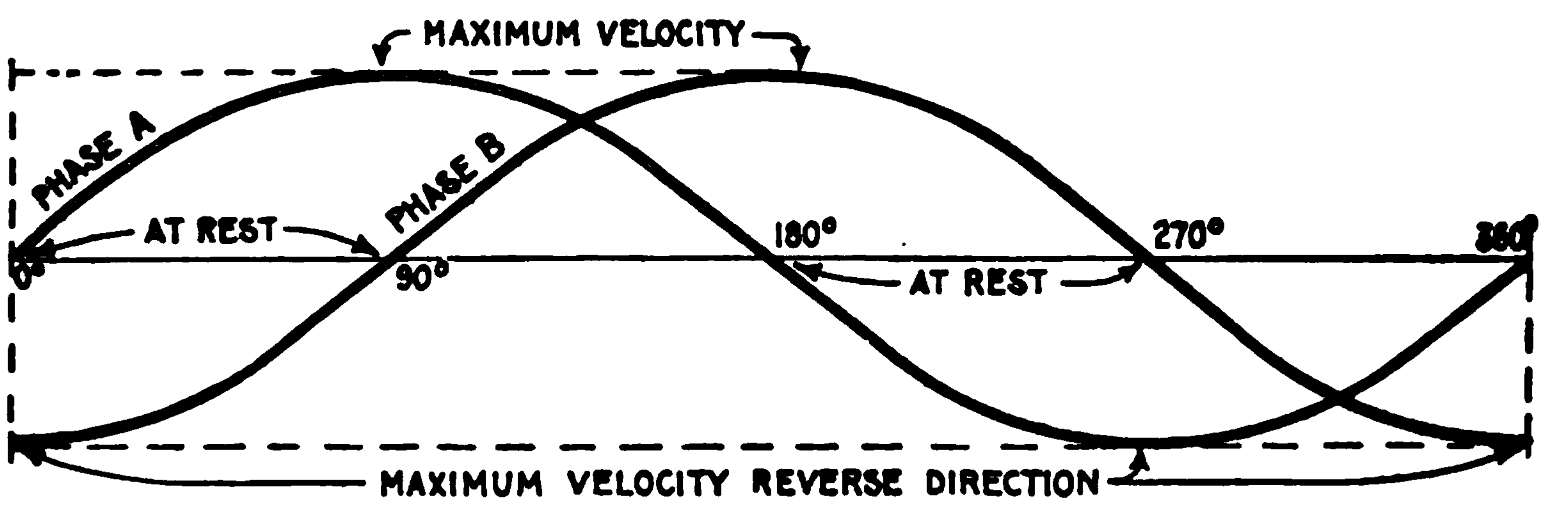
Ques. How must an alternator be constructed to generate two phase current?

Ans. It must have two independent windings, and these must be so spaced out that when the volts generated in one of the two phases are at a maximum, those generated in the other are at zer

[redacted]

In other words, the windings, which must be alike, of an equal number of turns, must be displaced along the armature by an angle corresponding to one-quarter of a period, that is, to half the pole pitch.





Figs. 1,254 and 1,255.—Hydraulic analogy illustrating two phase alternating current. In the figure two cylinders, similar to the one in fig. 1,251, are shown, operated from one shaft by crank and Scotch yoke drive. The cranks are at 90° as shown, and the cylinders and connecting pipes full of water. In operation, the same cycle of water flow takes place as in fig. 1,251. Since the cranks are at 90°, the second piston is one-half stroke behind the first; the flow of water in No. 1 (phase A) is at a maximum when the flow in No. 2 (phase B) comes to rest, the current conditions in both pipes for the entire cycle being represented by the two sine curves whose phase difference is 90°. Comparing these curves with fig. 1,253, it will be seen that the water and electric current act in a similar manner.

The windings of the two phases must, of course, be kept separate, hence the armature will have four terminals, or if it be a revolving armature it will have four collector rings.

As must be evident the phase difference may be of any value between 0° and 360°, but in practice it is almost always made 90°.

Ques. In what other way may two phase current be generated?

Ans. By two single phase alternators coupled to one shaft.

Ques. How many wires are required for two phase distribution?

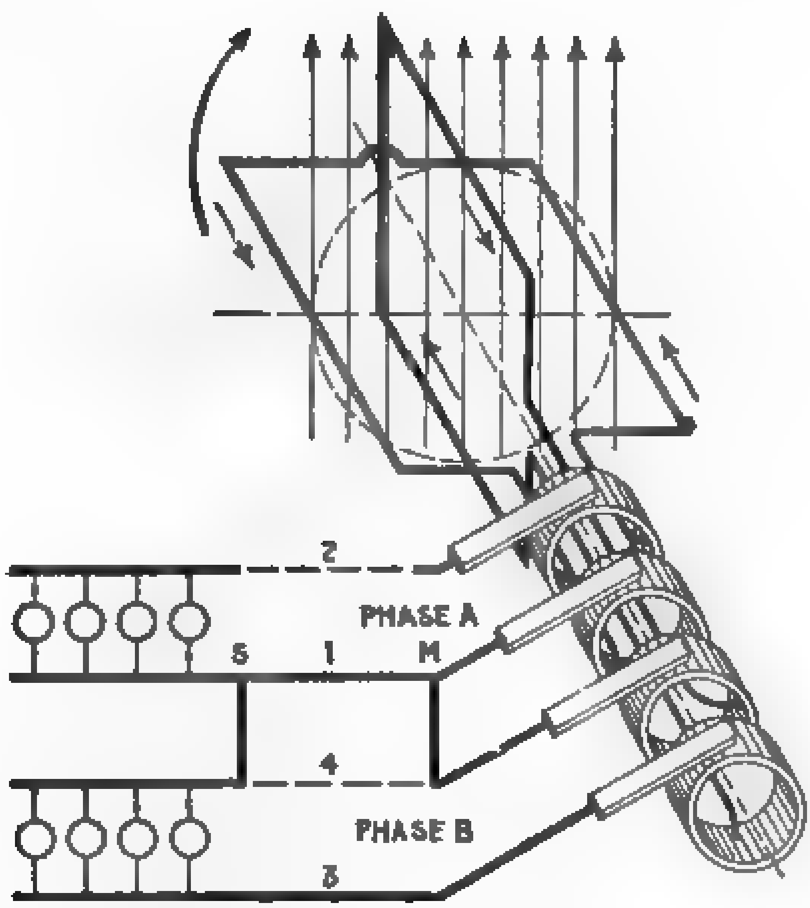


FIG. 1,256.—Diagram of three wire two phase current distribution. In order to save one wire it is possible to use a common return conductor for both circuits, as shown, the dotted portion of one wire 4 being eliminated by connecting across to 1 at M and S. For long lines this is economical, but the interconnection of the circuits increases the chance of trouble from grounds or short circuits. The current in the conductor will be the resultant of the two currents, differing by 90° in phase.

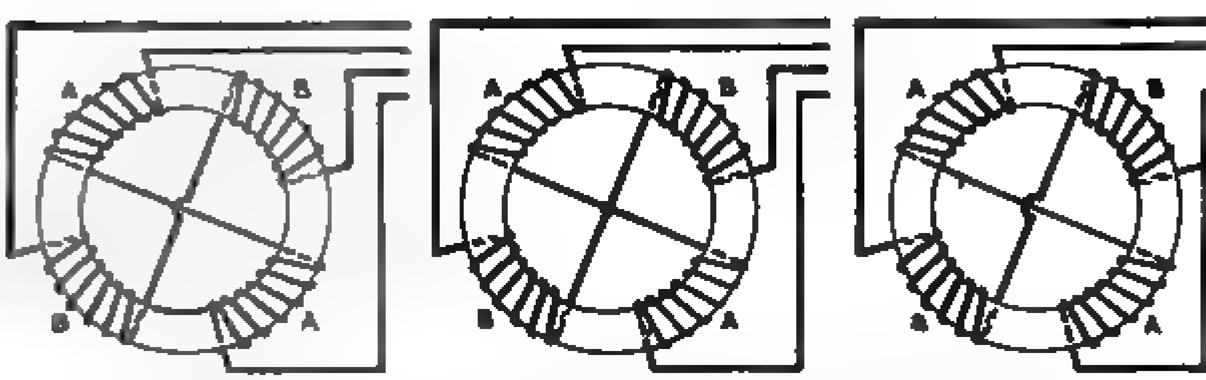
Ans. A two phase system requires four lines for its distribution; two lines for each phase as in fig. 1,253. It is possible, but *not advisable,* to reduce the number to 3, by employing one *rather thicker line* as a common return for each of the phases *as in fig. 1,256.*

[redacted]

If this be done, the voltage between the A line and the B line will be equal to $\sqrt{2}$ times the voltage in either phase, and the current in the line used as common return will be $\sqrt{2}$ times as great as the current in either line, assuming the two currents in the two phases to be equal.

Ques. In what other way may two phase current be distributed?

Ans. The mid point of the windings of the two phases may be united in the alternator at a common junction.



FIGS. 1,257 to 1,259—Various two phase armature connections. Fig. 1,257, two separate circuit four collector ring arrangement; fig. 1,258, common middle connection, four collector rings; fig. 1,259, circuit connected in armature for three collector rings. In the figures the black winding represents phase A, and the light winding, phase B.

This is equivalent to making the machine into a four phase alternator with half the voltage in each of the four phases, which will then be in successive quadrature with each other.

Ques. How are two phase alternator armatures wound?

Ans. The two circuits may be separate, each having two collector rings, as shown in fig. 1,257, or the two circuits may be coupled at a common middle as in fig. 1,258, or the two circuits may be coupled in the armature so that only three collector rings are required as shown in fig. 1,259.

Three Phase Current.—A three phase current consists of three alternating currents of equal frequency and amplitude, but differing in phase from each other by one-third of a period. Three phase current as represented by sine curves is shown in fig. 1,260, and by hydraulic analogy in fig. 1,262. Inspection of the

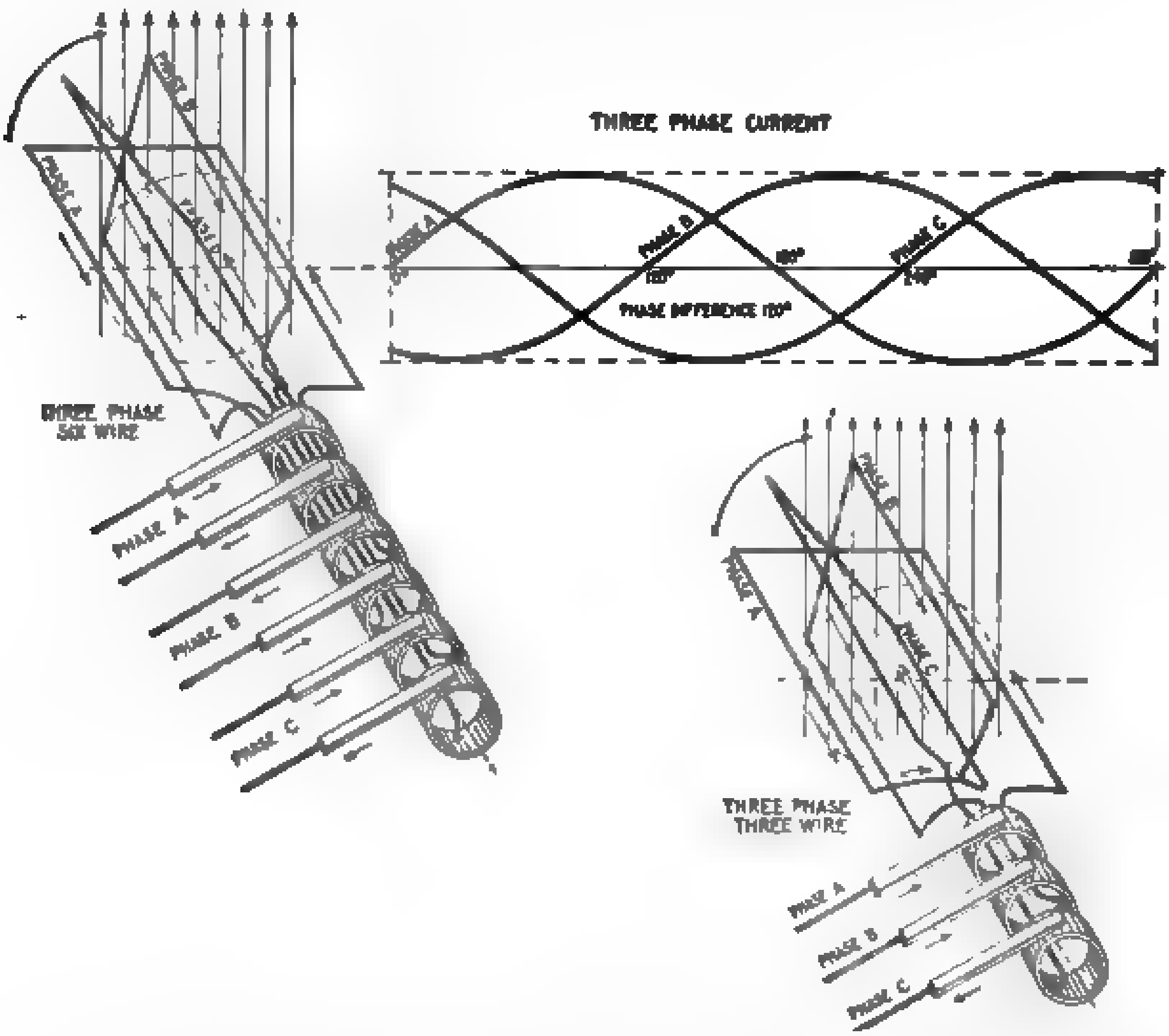


FIG. 1,260.—Elementary three loop alternator and sine curves, illustrating three phase alternating current. If the loops be placed on the alternator armature at 120 magnetic degrees from one another, the current in each will attain its maximum at a point one-third of a cycle distant from the other two. The arrangement here shown gives three independent single phase currents and requires six wires for their transmission. A better arrangement and the one generally used is shown in fig. 1,261.

FIG. 1,261.—Elementary three wire three phase alternator. For the transmission of three phase current, it is not customary to use six wires, as in fig. 1,260, instead, three ends (one end of each of the loops) are brought together to a common connection as shown, *and the other ends, connected to the collector rings, giving only three wires for the transmission of the current.*

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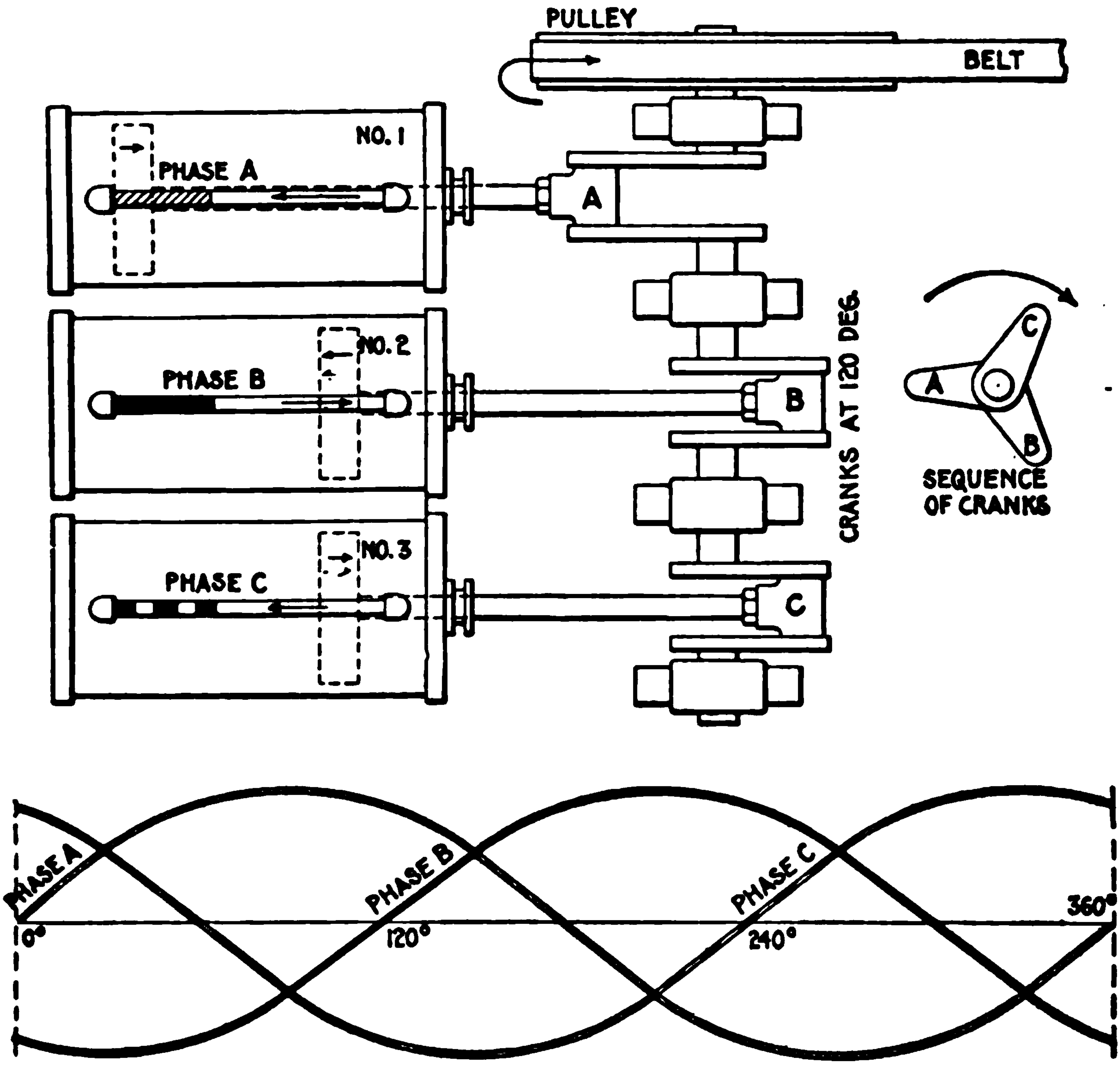
figures will show that when any one of the currents is at its maximum, the other two are of half their maximum value, and are flowing in the opposite direction.



FIGS. 1,262 and 1,263.—Hydraulic analogy illustrating three phase alternating current. Three cylinders are here shown with pistons connected through Scotch yokes to cranks placed 120° apart. The same action takes place in each cylinder as in the preceding cases, the only difference being the additional cylinder, and difference in phase relation.

Ques. How is three phase current generated?

Ans. It requires three equal windings on the alternator armature, *and they must be spaced* out over its surface so as

to be successively ⅓ and ⅔ of the period (that is, of the double pole pitch) apart from one another.

Ques. How many wires are used for three phase distribution?

Ans. Either six wires or three wires.

Six wires, as in fig. 1,260, might be used where it is desired to supply entirely independent circuits, or as is more usual only three wires are used as shown in fig. 1,261. In this case it should be observed that if the voltage generated in each one of the three phases separately E (virtual) volts, the voltage generated between any two of the terminals will be equal to $\sqrt{3} \times E$. Thus, if each of the three phases generate 100 volts, the voltage from the terminal of the A phase to that of the B phase will be 173 volts.

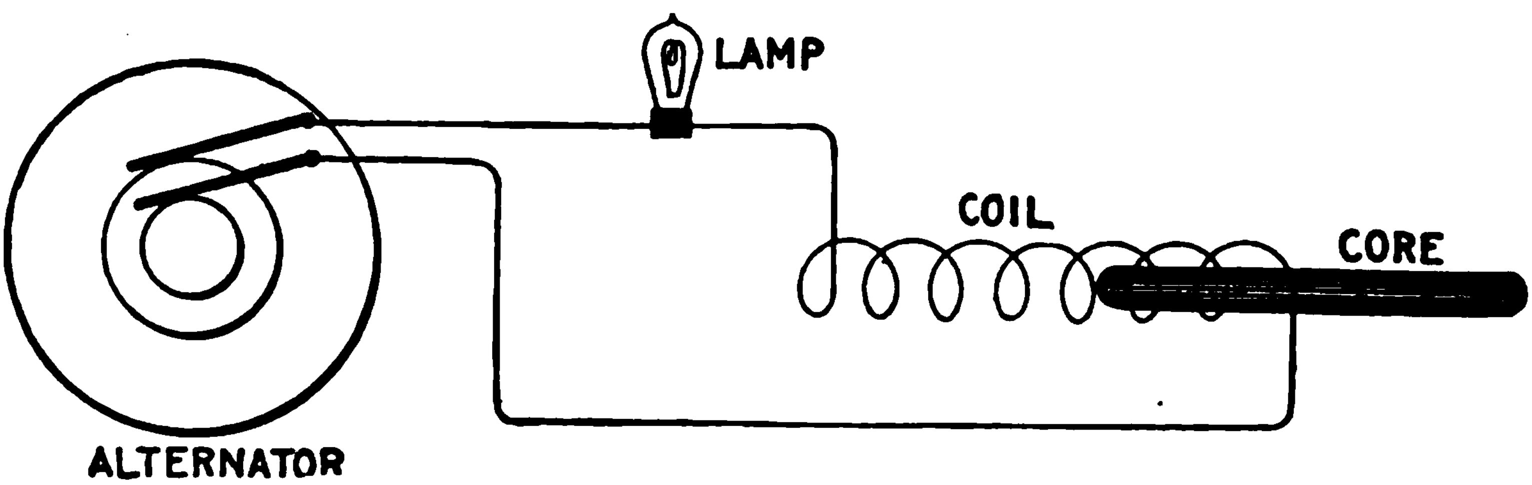


FIG. 1,264.—Experiment illustrating *self-induction* in an alternating current circuit. If an incandescent lamp be connected in series with a coil made of one pound of No. 20 magnet wire. and connected to the circuit, the current through the lamp will be decreased due to the self-induction of the coil. If now an iron core be gradually pushed into the coil, the self-induction will be greatly increased and the lamp will go out, thus showing the great importance which self-induction plays in alternating current work.

Inductance.—Each time a direct current is started, stopped or varied in strength, the magnetism changes, and induces or tends to induce a pressure in the wire which always has a direction opposing the pressure which originally produced the current. *This self-induced pressure tends to weaken the main current at the start and prolong it when the circuit is opened.*

The expression *inductance* is frequently used in the same sense as *coefficient of self-induction,* which is a quantity pertaining to an electric

circuit depending on its geometrical form and the nature of the surrounding medium.

If the direct current maintain the same strength and flow steadily, *there will be no variations in the magnetic field surrounding the wire and no self-induction*, consequently the only retarding effect of the current will be the " *ohmic resistance* " of the wire.

If an alternating current be sent through a circuit, there will be two retarding effects:

1. The *ohmic* resistance;
2. The *spurious* resistance.

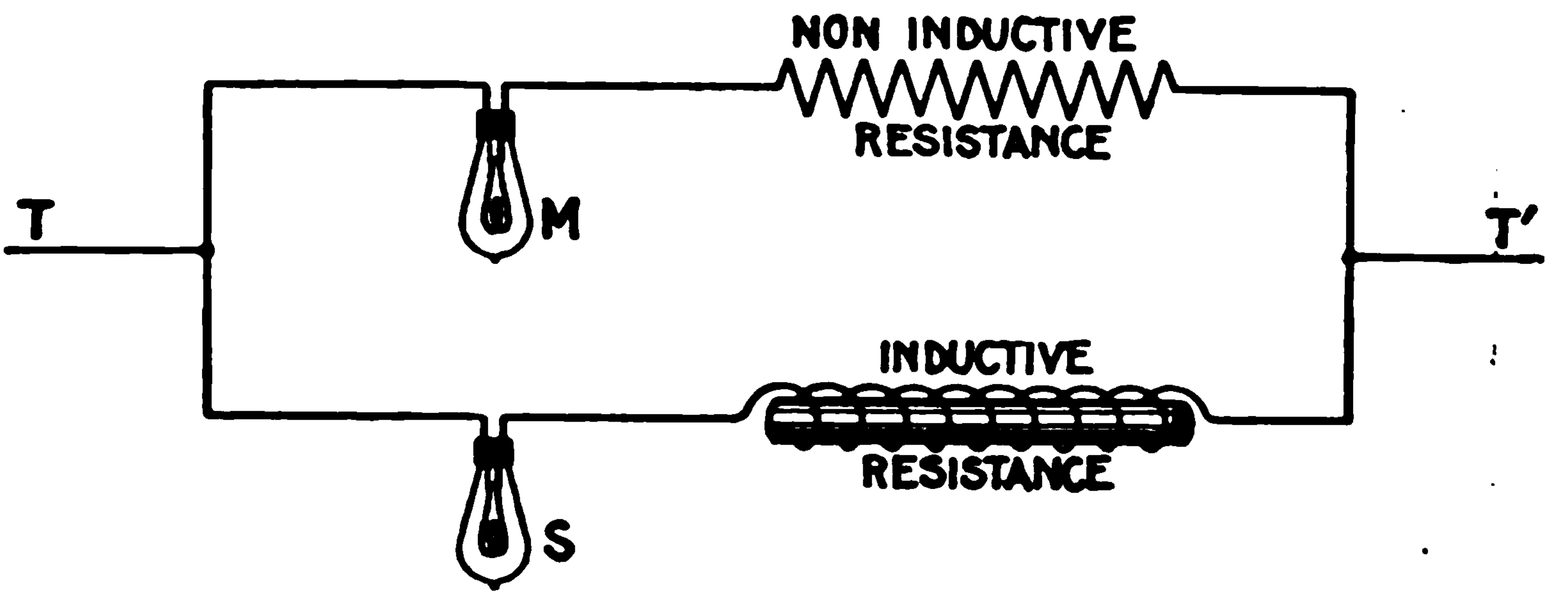


FIG. 1,265.—Non-inductive and inductive resistances. Two currents are shown joined in parallel, one containing a lamp and non-inductive resistance, and the other a lamp and inductive resistance. The two resistances being the same, a sufficient direct pressure applied at T, T′ will cause the lamps to light up equally. If, however, an alternating pressure be applied, M will burn brightly, while S will give very little or no light because of the effect of the inductance of the inductive resistance.

Ques. Upon what does the ohmic resistance depend?

Ans. Upon the length, cross sectional area and material of the wire.

Ques. Upon what does the spurious resistance depend?

Ans. Upon the frequency of the alternating current, the shape of the conductor, and nature of the surrounding medium

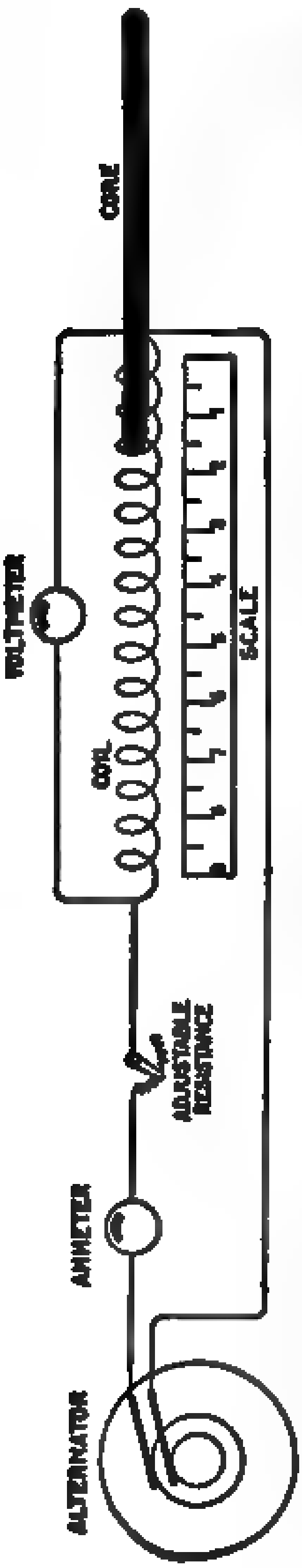


FIG. 1,206.—Inductance test, illustrating the self-induction of a coil which is gradually increased by moving an iron wire core inch by inch into the coil. The current is kept constant with the adjustable resistance throughout the test and readings taken, first without the iron core, and again when the core is put in the coil and moved to the 1, 2, 3, 4, etc., inch marks. By plotting the voltmeter readings and the position of the iron core on section paper, a curve is obtained showing graphically the effect of the self-induction. A curve of this kind is shown in fig. 1,302.

Ques. Define inductance.

Ans. It is the total magnetic flux threading the circuit per unit current which flows in the circuit, and which produces the flux.

In this it must be understood that if any portion of the flux thread the circuit more than once, this portion must be added in as many times as it makes linkage.

Inductance, or the coefficient of self-induction is the capacity which an electric circuit has of producing induction within itself.

Inductance is considered as the ratio between the total induction through a circuit to the current producing it.

Ques. What is the unit of inductance?

Ans. The henry.

Ques. Define the henry.

Ans. A coil has an inductance of one henry when the product of the number of lines enclosed by the coil multiplied by the number of turns in the coil, when a current of one ampere is flowing in the coil, is equal to 100,000,000 or $10.^8$

An inductance of one henry exists in a circuit *when a current changing at the rate of one ampere per second induces a pressure of one volt in the circuit.*

Ques. What is the henry called?

Ans. The coefficient of self-induction.

The henry is the coefficient by which the time rate of change of the current in the circuit must be multiplied, in order to give the pressure of self-induction in the circuit.

The formula for the henry is as follows:

$$\text{henrys} = \frac{\text{magnetic flux} \times \text{turns}}{\text{current} \times 100{,}000{,}000}$$

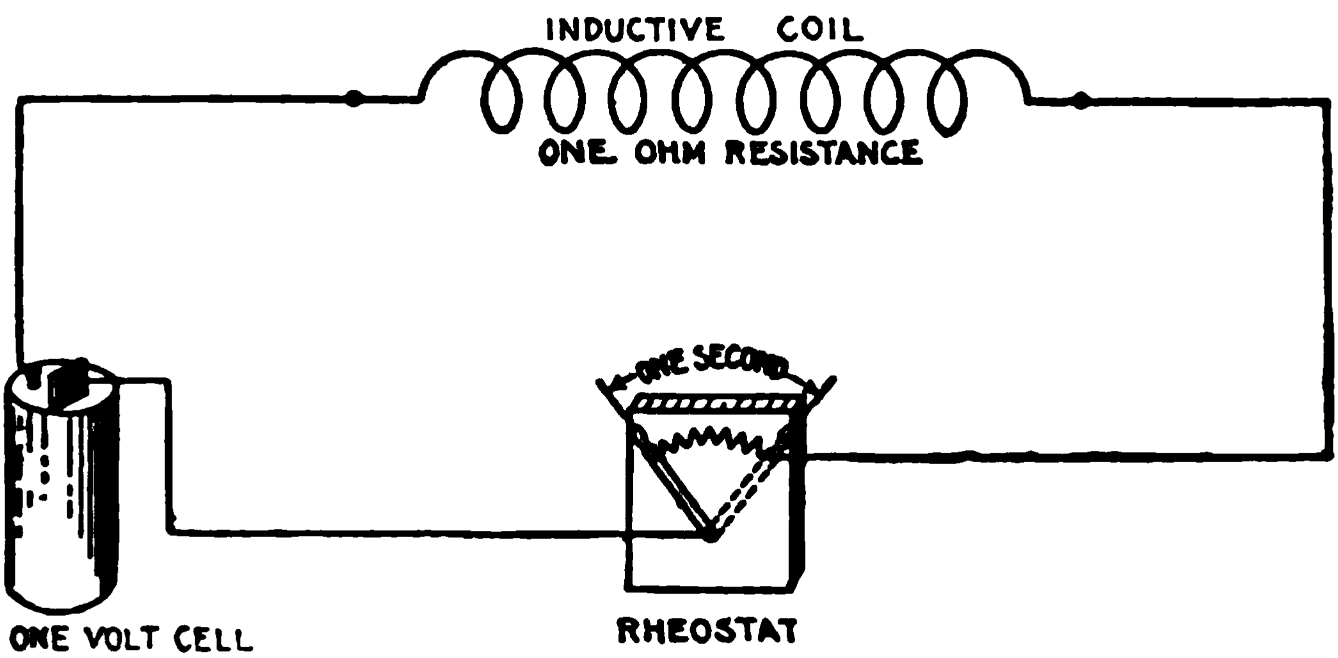


FIG. 1,267.—Diagram illustrating the henry. By definition: *A circuit has an inductance of one henry when a rate of change of current of one ampere per second induces a pressure of one volt.* In the diagram it is assumed that the internal resistance of the cell and resistance of the connecting wires are zero.

or

$$L = \frac{N \times T}{10^8} \qquad (1)$$

where

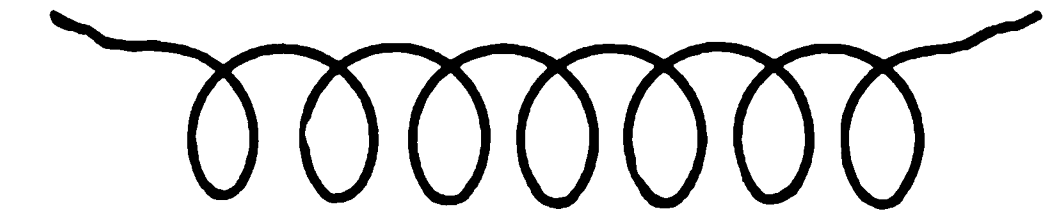
L = coefficient of self induction in henrys;

N = total number of lines of force threading a coil when the current is one ampere;

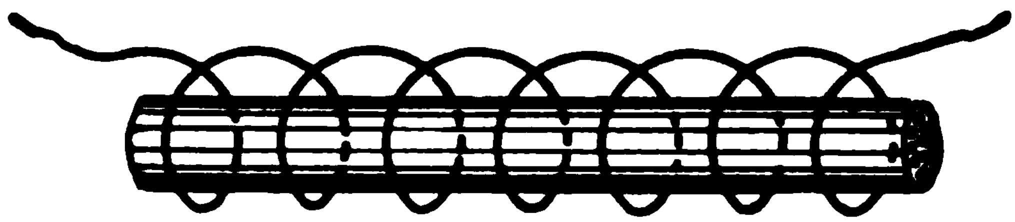
T = number of turns of coil.

If a coil had a coefficient of self-induction of one henry, it would mean that if the coil had one turn, one ampere would set up 100,000,000, or 10^8, lines *through it.*

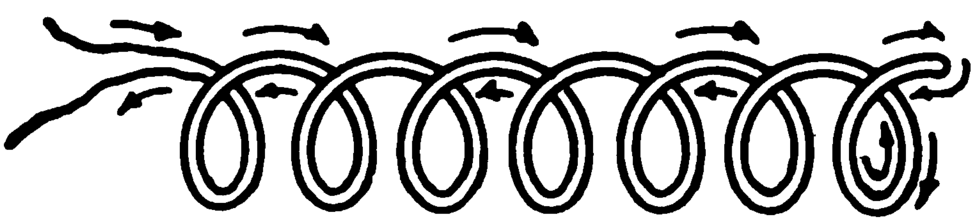
The henry is too large a unit for use in practical computations, which involves that the millihenry, or $\frac{1}{1,000}$th henry, is the accepted unit. In pole suspended lines the



INDUCTIVE COIL WITH AIR CORE



INDUCTIVE COIL WITH IRON CORE



NON-INDUCTIVE COIL

FIGS. 1,268 to 1,270.—Various coils. The inductance effect, though perceptible in an air core coil, fig. 1,268, may be greatly intensified by inserting a core made of numerous pieces of iron wire, as in fig. 1,269. Fig. 1,270 shows a non-inductive coil. When wound in this manner, a coil will have little or no inductance because each half of the coil neutralizes the magnetic effect of the other. This coil, though non-inductive, will have "capacity." It would be useless for solenoids or electro-magnets, as it would have no magnetic field.

NOTE.—The American physicist, Joseph Henry, was born in 1798 and died 1878. He was noted for his researches in electromagnetism. He developed the electromagnet, which had been invented by Sturgeon in England, so that it became an instrument of far greater power than before. In 1831, he employed a mile of fine copper wire with an electromagnet, causing the current to attract the armature and strike a bell, thereby establishing the principle employed in modern telegraph practice. He was made a professor at Princeton in 1832, and while experimenting at that time, he devised an arrangement of batteries and electromagnets embodying the principle of the telegraph relay which made possible long distance transmission. He was the first to observe magnetic self-induction, and performed important investigations in oscillating electric discharges (1842), and other electrical phenomena. In 1846 he was chosen secretary of the Smithsonian Institution at Washington, an office which he held until his death. As chairman of the U. S. Lighthouse Board, he made important tests in marine signals and lights. In meteorology, terrestrial magnetism, and acoustics, he carried on important researches. Henry *enjoyed an international reputation*, and is acknowledged to be one of America's greatest *scientists*.

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inductance varies as the metallic resistance, the distance between the wires on the cross arm and the number of cycles per second, as indicated by accepted tables. Thus, for one mile of No. 8 B. & S. copper wire, with a resistance of 3,406 ohms, the coefficient of self-induction with 6 inches between centers is .00153, and, with 12 inches, .00175.

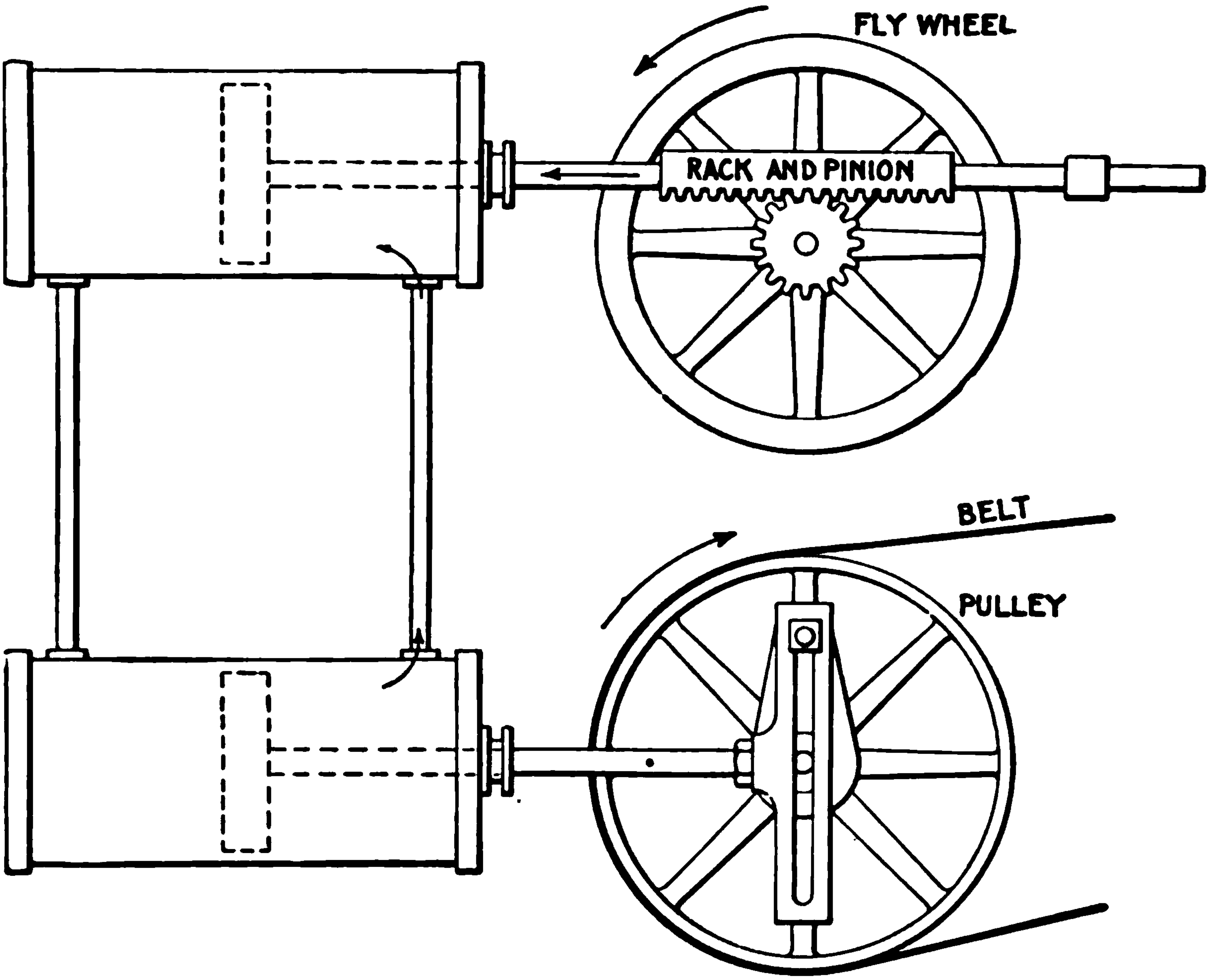


FIG. 1,271.—Hydraulic-mechanical analogy illustrating *inductance* in an alternating current circuit. The two cylinders are connected at their ends by the vertical pipes, each being provided with a piston and the system filled with water. Reciprocating motion is imparted to the lower pulley by Scotch yoke connection with the drive pulley. The upper piston is connected by rack and pinion gear with a fly wheel. In operation, the to and fro movement of the lower piston produces an alternating flow of water in the upper cylinder which causes the upper piston to move back and forth. The rack and pinion connection with the fly wheel causes the latter to revolve first in one direction, then in the other, in step with the upper piston. The inertia of the fly wheel causes it to resist any change in its state, whether it be at rest or in motion, which is transmitted to the upper piston, causing it to offer resistance to any change in its rate or direction of motion. Inductance in the alternating current circuit has precisely the same effect, that is, it opposes any *change in the strength or direction of the current.*

Ques. How does the inductance of a coil vary with respect to the core?

Ans. It is least with an air core; with an iron core, it is greater in proportion to the permeability* of the iron.

The coefficient L for a given coil is a constant quantity so long as the magnetic permeability of the material surrounding the coil does not change. This is the case where the coil is surrounded by air. When iron is present, the coefficient L is practically constant, provided the magnetism is not forced too high.

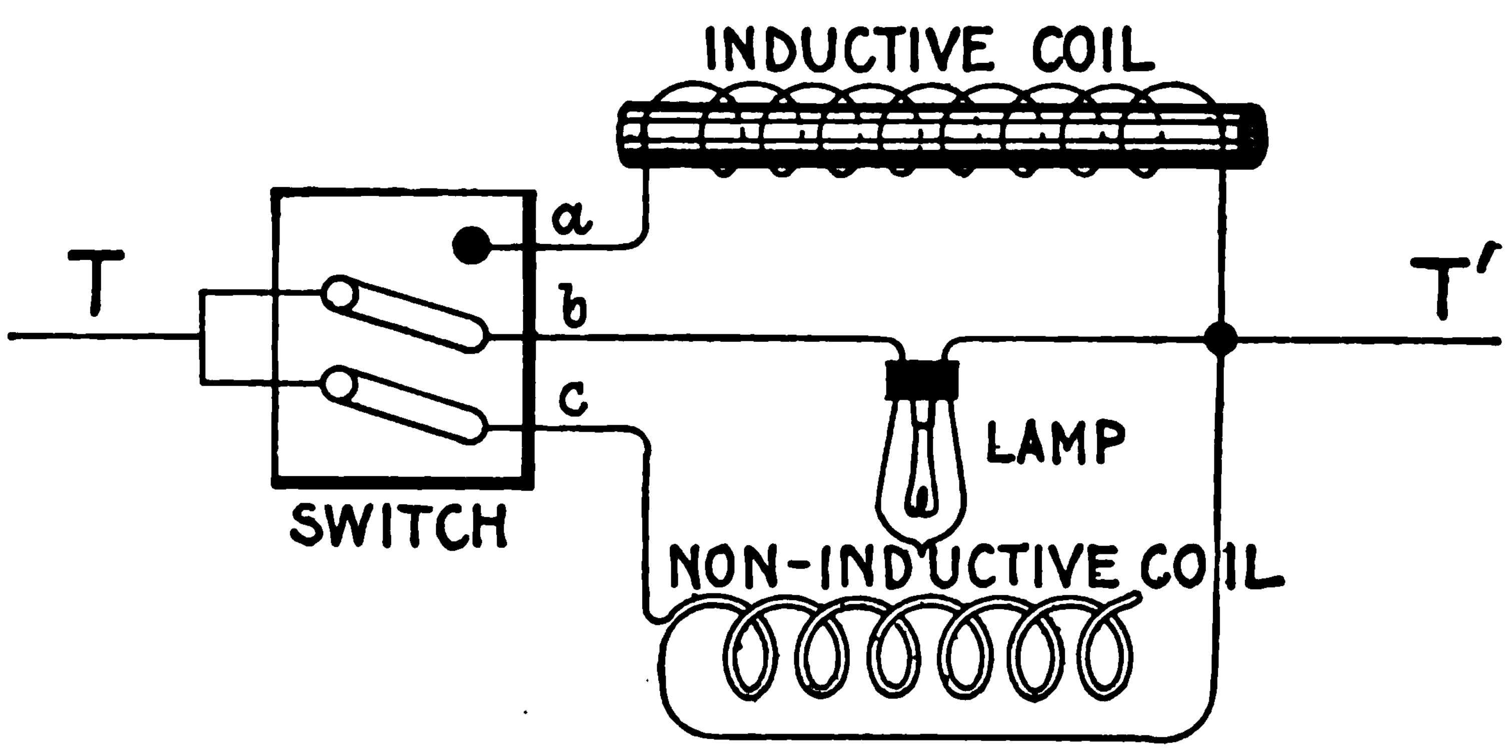


FIG. 1,272.—Experiment showing effect of inductive and non-inductive coils in alternating current circuit. The apparatus is connected up as shown; by means of the switch, the lamp may be placed in parallel with either the inductive or non-inductive coil. These coils should have the same resistance. Pass an alternating current through the lamp and non-inductive coil, of such strength that the lamp will be dimly lighted. Now turn the switch so as to put the lamp and inductive coil in parallel and the lamp will burn with increased brilliancy. The reason for this is because of the opposition offered by the inductive coil to the current, less current is shunted from the lamp when the inductive coil is in the circuit than when the non-inductive coil is in the circuit. That is, each coil has the same ohmic resistance, but the inductive coil has in addition the spurious resistance due to inductance, hence it shunts less current from the lamp than does the non-inductive coil.

In most cases arising in practice, the coefficient L may be considered to be a constant quantity, just as the resistance R is usually considered constant. The coefficient L of a coil or circuit is often spoken of as its *inductance*.

NOTE.—The permeability of iron varies from 500 to 1,000 or more. The permeability of a given sample of iron is not constant, but decreases in value as the magnetizing force increases. Therefore the inductance of a coil having an iron core is not a constant quantity as is the inductance of an air core coil.

[redacted]

Ques. Why is the iron core of an inductive coil made with a number of small wires instead of one large rod?

Ans. It is laminated in order to reduce eddy currents and consequent loss of energy, and to prevent excessive heating of the core.

Ques. How does the number of turns of a coil affect the inductance?

Ans. The inductance varies as the square of the turns.

That is, if the turns be doubled, the inductance becomes four times as great.

The inductance of a coil is easily calculated from the following formulæ:

$$L = 4\pi^2 r^2 n^2 \div (l \times 10^9) \quad \ldots\ldots\ldots\ldots (1)$$

for a thin coil with air core, and

$$L = 4\pi^2 r^2 n^2 \mu \div (l \times 10^9) \quad \ldots\ldots\ldots\ldots (2)$$

for a coil having an iron core. In the above formulæ:

L = inductance in henrys;
π = 3.1416;
r = average radius of coil in centimeters;
n = number of turns of wire in coil;
μ = permeability of iron core;
l = length of coil in centimeters.

EXAMPLE.—An air core coil has an average radius of 10 centimeters and is 20 centimeters long, there being 500 turns, what is the inductance?

Substituting these values in formula (1)

$$L = 4 \times (3.1416)^2 \times 10^2 \times 500^2 \div (20 \times 10^9) = .00494 \text{ henry}$$

Ques. Is the answer in the above example in the customary form?

Ans. No; the henry being a very large unit, it is usual to express inductance in thousandths of a henry, that is, in *milli-henrys*. The answer then would be .04935 × 1,000 = 49 35 milli-henrys.

FIGS. 1,273 to 1,275.—General Electric choke coils. Fig 1,273, hour glass coil, 35,000 volts; fig. 1,274, 4,600 volt coil; fig. 1,275, 6,600 volt coil. A choke coil is *a coil with large inductance and small resistance, used to impede alternating currents.* The choke coil is used extensively as an auxiliary to the lightning arrester. In this connection the primary objects of the choke coil should be 1, to hold back the lightning disturbance from the transformer or generator until the lightning arrester discharges to earth. If there be no lightning arrester the choke coil evidently cannot perform this function. 2, to lower the frequency of the oscillation so that whatever charge gets through the choke coil will be of a frequency too low to cause a serious drop of pressure around the first turns of the end coil in either generator or transformer. Another way of expressing this is from the standpoint of wave front: a steep wave front piles up the pressure when it meets an inductance. The second function of the choke coil is, then, to smooth out the wave front of the surge. The principal electrical condition to be avoided is that of resonance. The coil should be so arranged that if continual surges be set up in the circuit, a resonant voltage due to the presence of the choke coil cannot build up at the transformer or generator terminals. In the types shown above, the hour glass coil has the following advantages on high voltages: 1, should there be any arcing between adjacent turns the coils will reinsulate themselves, 2, they are mechanically strong, and sagging is prevented by tapering the coils toward the center turns, 3, the insulating supports can be best designed for the strains which they have to withstand. Choke coils should not be used in connection with cable systems.

EXAMPLE.—An air core coil has an inductance of **50 milli-henrys**; if an iron core, having a permeability of 600 be inserted, what is the inductance?

The inductance of the air core coil will be multiplied by the *permeability of the iron;* the inductance then is increased to

$$50 \times 600 = 30{,}000 \text{ milli-henrys, or } 30 \text{ henrys.}$$

Ohmic Value of Inductance.—The rate of change of an alternating current at any point expressed in degrees is equal to the product of 2π *multiplied by the frequency, the maximum current, and the cosine of the angle of position* θ; that is (using symbols)

$$\text{rate of change} = 2\pi f \, I_{max} \cos\theta.$$

The numerical value of the rate of change is independent of its positive or negative sign, so that the sign of the $\cos\phi$ is disregarded.

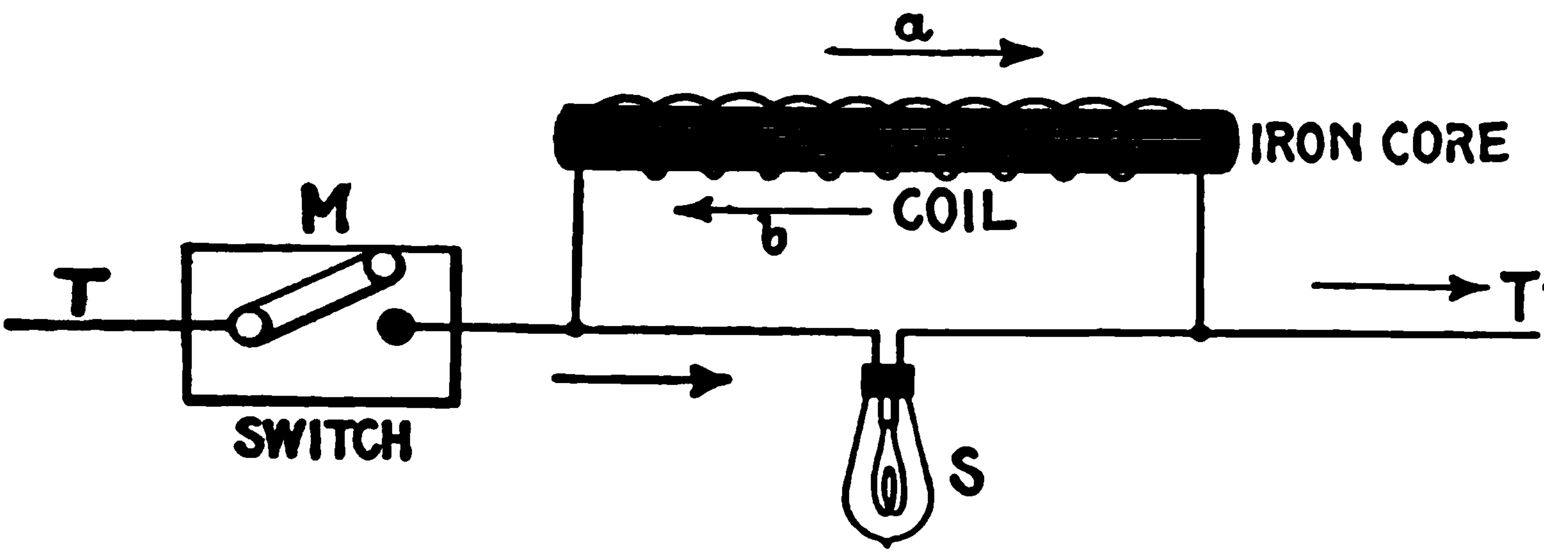


FIG. 1,276.—Inductance experiment with intermittent direct current. A lamp S is connected in parallel with a coil of fairly fine wire having a removable iron core, and the terminals T, T' connected to a source of direct current, a switch M being provided to interrupt the current. The voltage of the current and resistance of the coil are of such values that when a steady current is flowing, the lamp filament is just perceptibly red. *At the instant of making the circuit, the lamp will momentarily glow more brightly than when the current is steady; on breaking the circuit the lamp will momentarily flash with great brightness.* In the first case, the reverse pressure, due to inductance, as indicated by arrow *b*, will momentarily oppose the normal pressure in the coil, so that the voltage at the lamp will be momentarily increased, and will consequently send a momentarily stronger current through the lamp. On breaking the main circuit at M, the field of the coil will collapse, generating a momentary much greater voltage than in the first instance, in the direction of arrow *a*, the lamp will flash up brightly in consequence.

The period of greatest rate of change is that at which $\cos\phi$ has the greatest value, and the maximum value of a cosine is when the arc has a value of zero degrees or of 180 degrees, its value corresponding, being 1. (See fig. 1,037, page 1,068.)

The pressure due to inductance is equal to the product of the rate of change by the inductance; that is, calling the inductance L,

the pressure due to it at the point of maximum value or

$$E_{max} = 2\,\pi f\, I_{max} \times L \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Now by Ohm's law

$$E_{max} = RI_{max} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

for a current I_{max}, hence substituting equation (2) in equation (1)

$$RI_{max} = 2\,\pi f\, I_{max} \times L$$

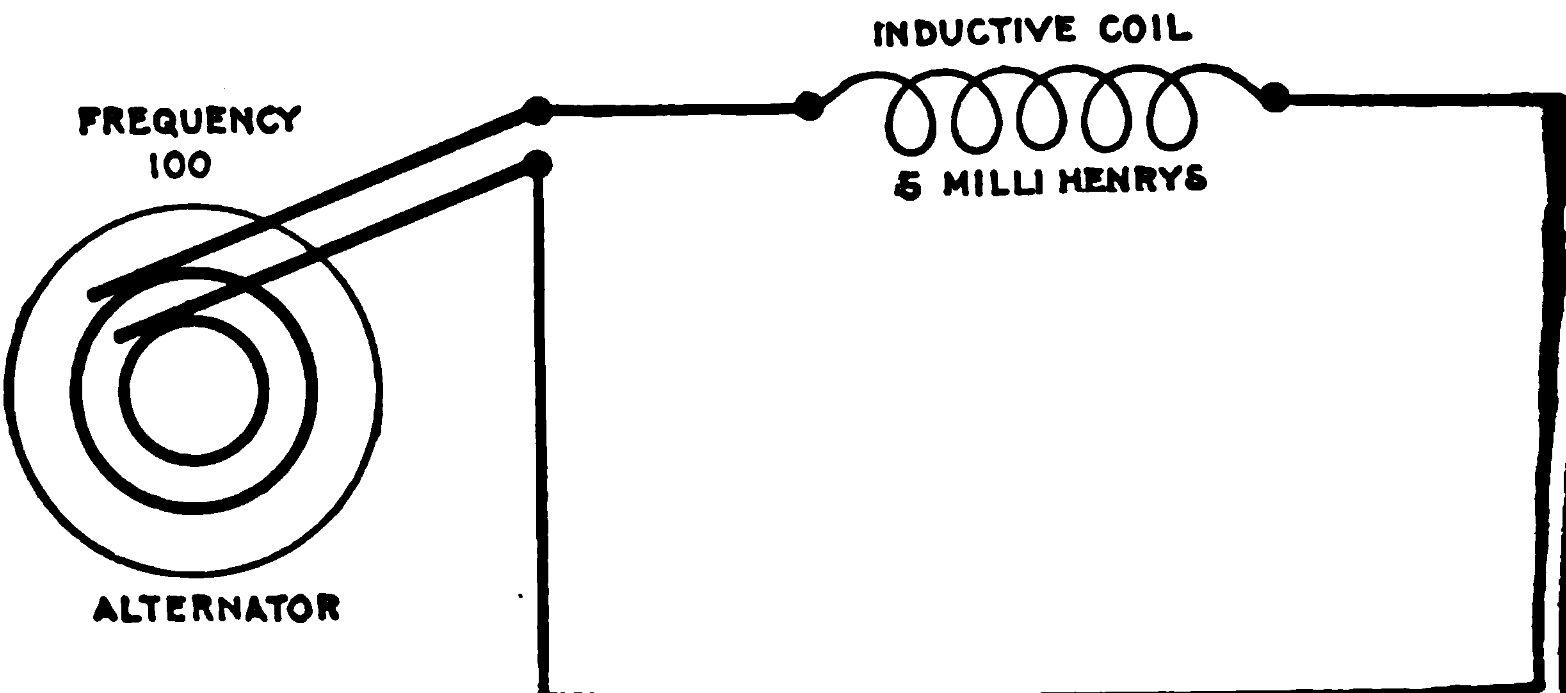


Fig. 1,277.—Diagram showing alternating circuit containing inductance. Formula for calculating the ohmic value of inductance or "inductance reactance," is $X_l = 2\,\pi f L$ in which X_l = inductance reactance; π = 3.1416; f = frequency; L = inductance *in henrys* (not millihenrys). L = 15 millihenrys = 15 ÷ 1000 = .015 henrys. Substituting, $X_l = 2 \times 3.1416 \times 100 \times .015 = 9.42$ ohms.

from which, dividing both sides by I_{max}, and using X_l for R

$$X_l = 2\,\pi f\, L \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

which is the **ohmic equivalent of inductance.**

The frequency of a current being the number of periods or waves per second, then, if T = the time of a period, the frequency

of a current may be obtained by dividing 1 second by the time of a period; that is

$$\text{frequency} = \frac{\text{one second}}{\text{time of one period}} = \frac{1}{T} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

substituting $\frac{1}{T}$ for f in equation (3)

$$X_l = 2\pi\frac{L}{T}$$

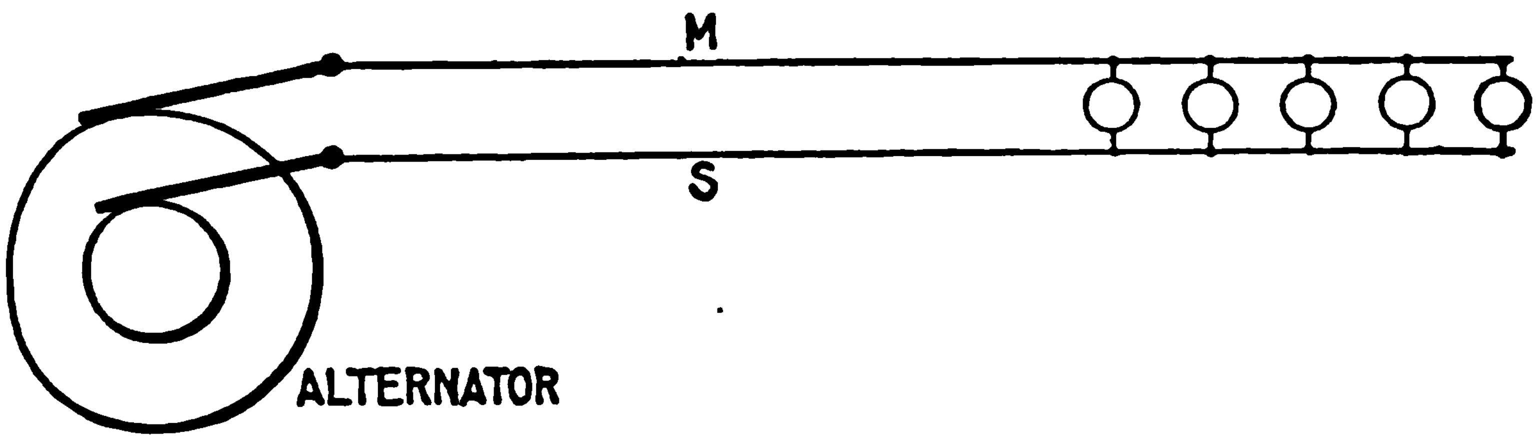


FIG. 1,278.—Diagram illustrating effect of capacity in an alternating circuit. Considering its action during one cycle of the current, the alternator first "pumps," say from M to S; electricity will be heaped up, so to speak, on S, and a deficit left on M, that is, S will be + and M —. If the alternator be now suddenly stopped, there would be a momentary return flow of electricity from S to M through the alternator. If the alternator go on working, however, it is obvious that the electricity heaped up on S helps or increases the flow when the alternator begins to pump from S to M in the second half of the cycle, and when the alternator again reverses its pressure, the + charge on M flows round to S, and helps the ordinary current. The above circuit is not strictly analogous to the insulated plates of a condenser, but, as is verified in practice, that with a rapidly alternating pressure, the condenser action is not perceptibly affected if the cables be connected across by some non-inductive resistance as for instance incandescent lamps.

Capacity.—When an electric pressure is applied to a condenser, the current plays in and out, charging the condenser in alternate directions. As the current runs in at one side and out at the other, the dielectric becomes charged, and tries to discharge itself by setting up an opposing electric pressure. This *opposing pressure rises just as the* charge increases.

A mechanical analogue is afforded by the bending of a spring, *as in fig. 1,279, which, as it is being* bent, exerts an opposing forc

equal to that applied, provided the latter do not exceed the capacity of the spring.

Ques. What is the effect of capacity in an alternating circuit?

Ans. It is exactly opposite to that of inductance, that is, it assists the current to rise to its maximum value sooner than it would otherwise.

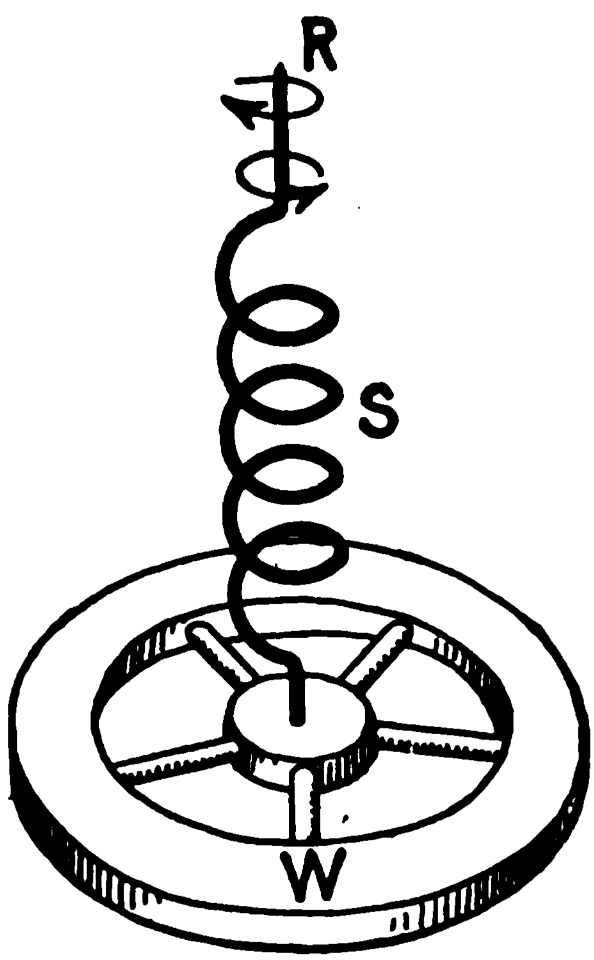


FIG. 1,279.—Mechanical analogy illustrating effect of capacity in an alternating circuit. If an alternating twisting force be applied to the top R of the spring S, the action of the latter may be taken to represent capacity, and the rotation of the wheel W, alternating current. The twisting force (impressed pressure) must first be applied *before* the rotation of W (current) will begin. The resiliency or rebounding effect of the spring will, in time, cause the wheel W to move (amperes) in advance of the twisting force (voltage), thus representing the current *leading in phase.*

Ques. Is it necessary to have a continuous metallic circuit for an alternating current?

Ans. No, it is possible for an alternating current to flow *through a circuit which* is divided at some point by insulating *material.*

Ques. How can the current flow under such condition?

Ans. Its flow depends on the capacity of the circuit and accordingly a condenser may be inserted in the circuit as in fig. 1,286, thus interposing an insulated gap, yet permitting an alternating flow in the metallic portion of the circuit.

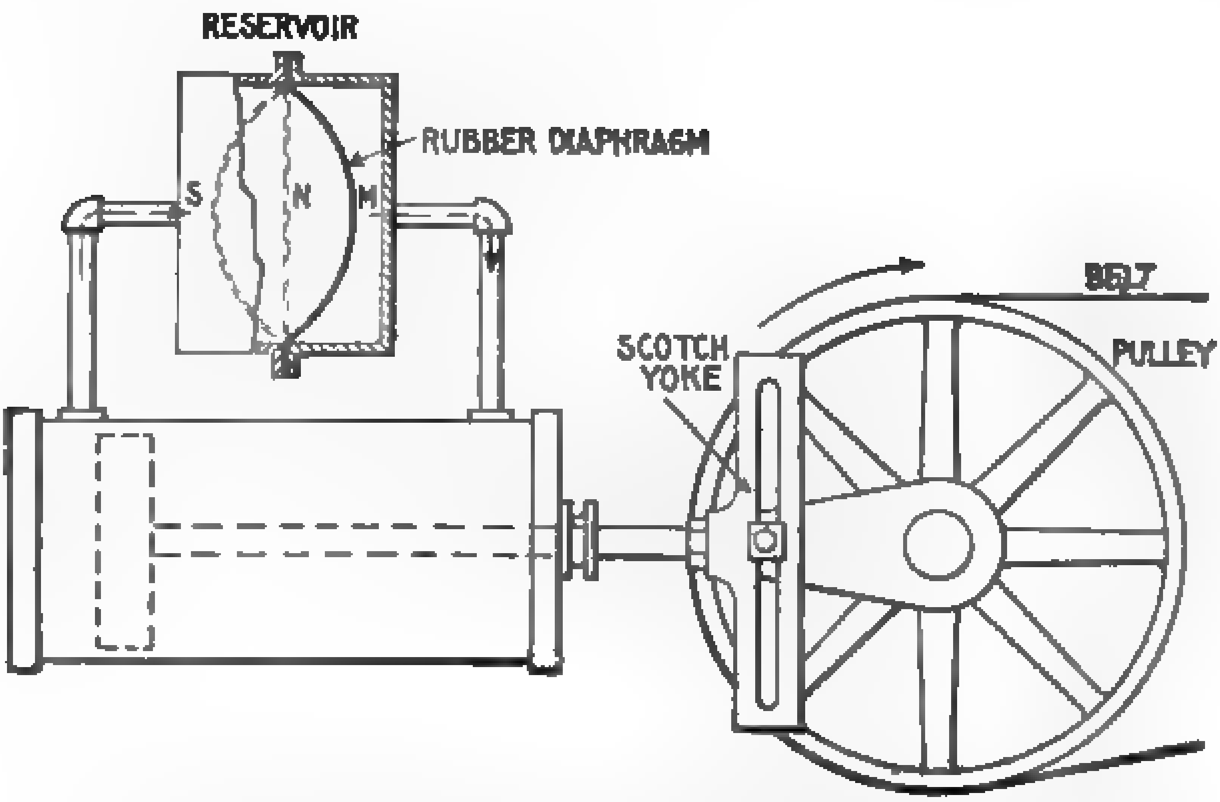


FIG. 1,286.—Hydraulic analogy illustrating capacity in an alternating current circuit. A chamber containing a rubber diaphragm is connected to a double acting cylinder and the system filled with water. In operation, as the piston moves, say to the left from the center, the diaphragm is displaced from its neutral position N, and stretched to some position M, in so doing offering increasing resistance to the flow of water. On the return stroke the flow is reversed and is assisted by the diaphragm during the first half of the stroke, and opposed during the second half. The diaphragm thus acts with the flow of water one-half of the time and in opposition to it one-half of the time. This corresponds to the electrical pressure at the terminals of a condenser connected in an alternating current circuit, and it has a maximum value when the current is zero and a zero value when the current is a maximum.

Ques. Name the unit of capacity and define it.

Ans. The unit of capacity is called the *farad* and its symbol C. A condenser is said to have a capacity of one farad if o coulomb (that is, *one ampere* flowing one second), when sto

on the plates of the condenser will cause a pressure of one volt across its terminals.

The farad being a very large unit, the capacities ordinarily encountered in practice are expressed in millionths of a farad, that is, in *micro-farads*—a capacity equal to about three miles of an Atlantic cable.

It should be noted that the microfarad is used only for convenience, and that *in working out problems, capacity should always be expressed in farads before substituting in formulæ,*

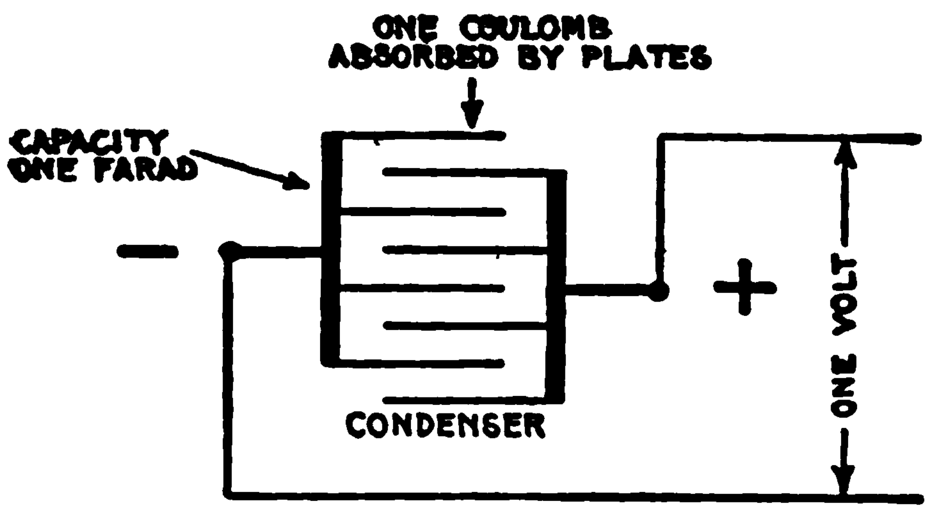


FIG. 1,281—Diagram illustrating a *farad*. A condenser is said to have a capacity of one farad if it will absorb one coulomb of electricity when subjected to a pressure of one volt. The farad is a very large unit, and accordingly the microfarad or one millionth of a farad is often used, though *this must be reduced to farads before substituting in formulæ.*

because the farad is chosen with respect to the volt and ampere, as above defined, and hence must be used in formulæ along with these units.

For instance, a capacity of 8 microfarads as given in a problem would be substituted in a formula as .000008 of a farad.

The charge Q forced into a condenser by a steady electric pressure E is

$$Q = E\ C$$

in which

Q = charge in coulombs.
E = electric pressure in volts;
C = capacity of condenser in farads;

Ques. What is the material between the plates of a condenser called?

Ans. The *dielectric.*

Ques. Upon what does the capacity of a condenser depend?

Ans. It is proportional to the area of the plates, and inversely proportional to the thickness of the dielectric between the plates, a correction being required unless the thickness of dielectric be very small as compared with the dimensions of the plates.

The capacity of a condenser is also proportional to the *specific inductive capacity* of the dielectric between the plates of the condenser.

FIG. 1,282.—Condenser of one microfarad capacity. It is subdivided into five sections of .5, .2, .2, .05 and .05 microfarad. The plates are mounted between and carried by lateral brass bars which are fastened to a hard rubber top. Each pair of condenser terminals is fastened to small binding posts mounted on hard rubber insulated posts.

Specific Inductive Capacity.—Faraday discovered that different substances have different powers of carrying lines of electric force. Thus the charge of two conductors having a given difference of pressure between them depends on the medium *between them as well as on their* size and shape. The number *indicating the magnitude of this* property of the medium is *called its specific inductive capacity,* or *dielectric constant.*

The specific inductive capacity of air, which is nearly the same as that of a vacuum, is taken as unity. In terms of this unit the following are some typical values of the dielectric constant: Water 80, glass 6 to 10, mica 6.7, gutta percha 3, india rubber 2.5, paraffin wax, 2, ebonite 2.5, castor oil 4.8.

In underground cables for very high pressures, the insulation, if homogeneous throughout, would have to be of very great thickness in order to have sufficient dielectric strength. By employing material of high specific inductive capacity close to the conductor, and material of lower specific inductive capacity toward the outside, that is, by *grading* the insulation, a considerably less total thickness affords equally high dielectric strength.

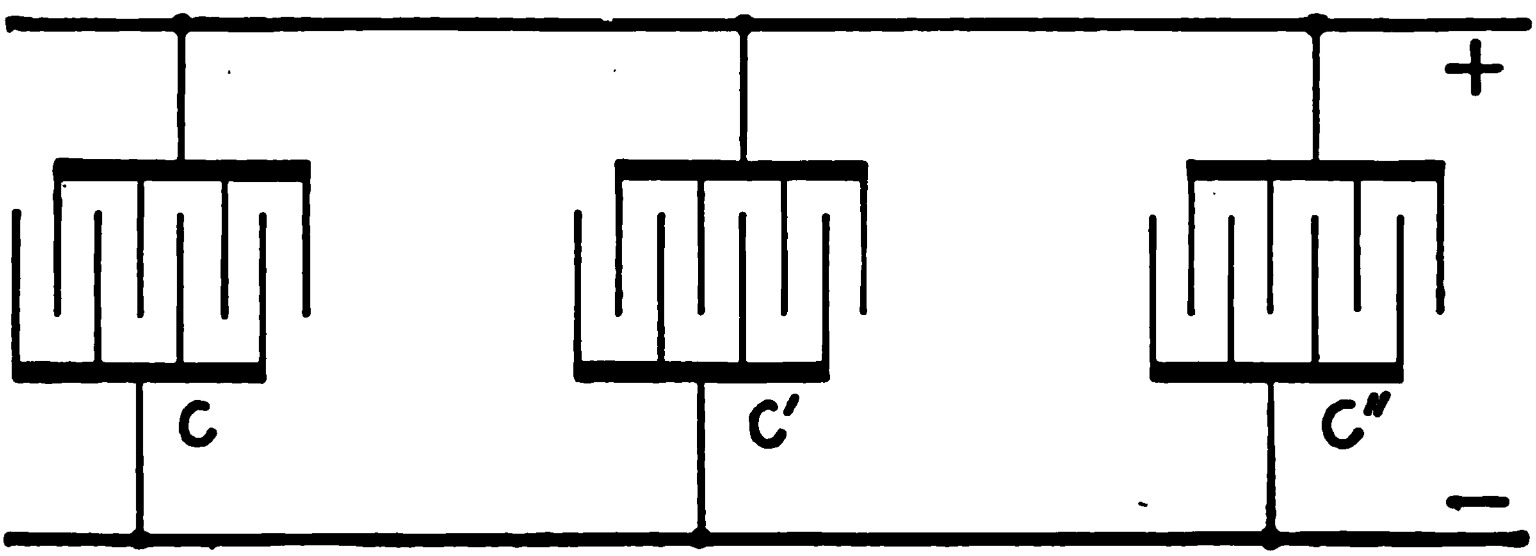


FIG. 1,283.—Parallel connection of condensers. Like terminals are joined together. The joint capacity of such arrangement is equal to *the sum of the respective capacities*, that is C = c + c′ + c″.

Ques. How are capacity tests usually made?

Ans. By the aid of standard condensers.

Ques. How are condensers connected?

Ans. They may be connected in parallel as in fig. 1,283, or in series (cascade) as in fig. 1,284.

Condensers are now constructed so that the two methods of arranging the plates may conveniently be combined in one condenser, thereby obtaining a wider range of capacity.

[redacted]

Ques. How may the capacity of a condenser, wire, or cable be tested?

Ans. This may be done by the aid of a standard condenser, trigger key, and an astatic or ballistic galvanometer.

In making the test, first obtain a " constant " by noting the deflection *d*, due to the discharge of the standard condenser after a charge of, say, 10 seconds from a given voltage. Then discharge the other condenser, wire, or cable through the galvanometer after 10 seconds charge, and note the deflection *d'*. The capacity C' of the latter is then

$$C' = C \times \frac{d'}{d}$$

in which C is the capacity of the standard condenser.

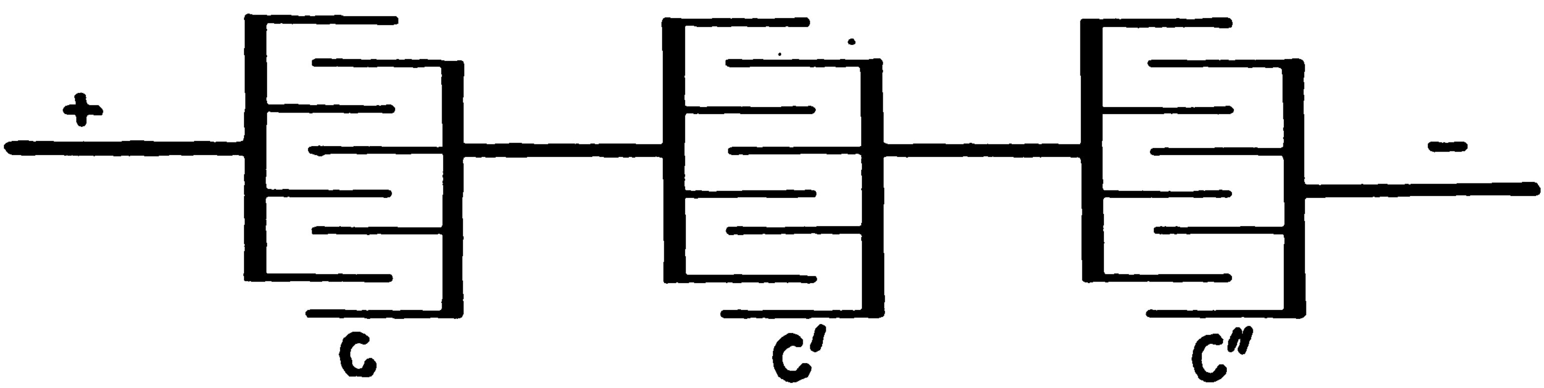


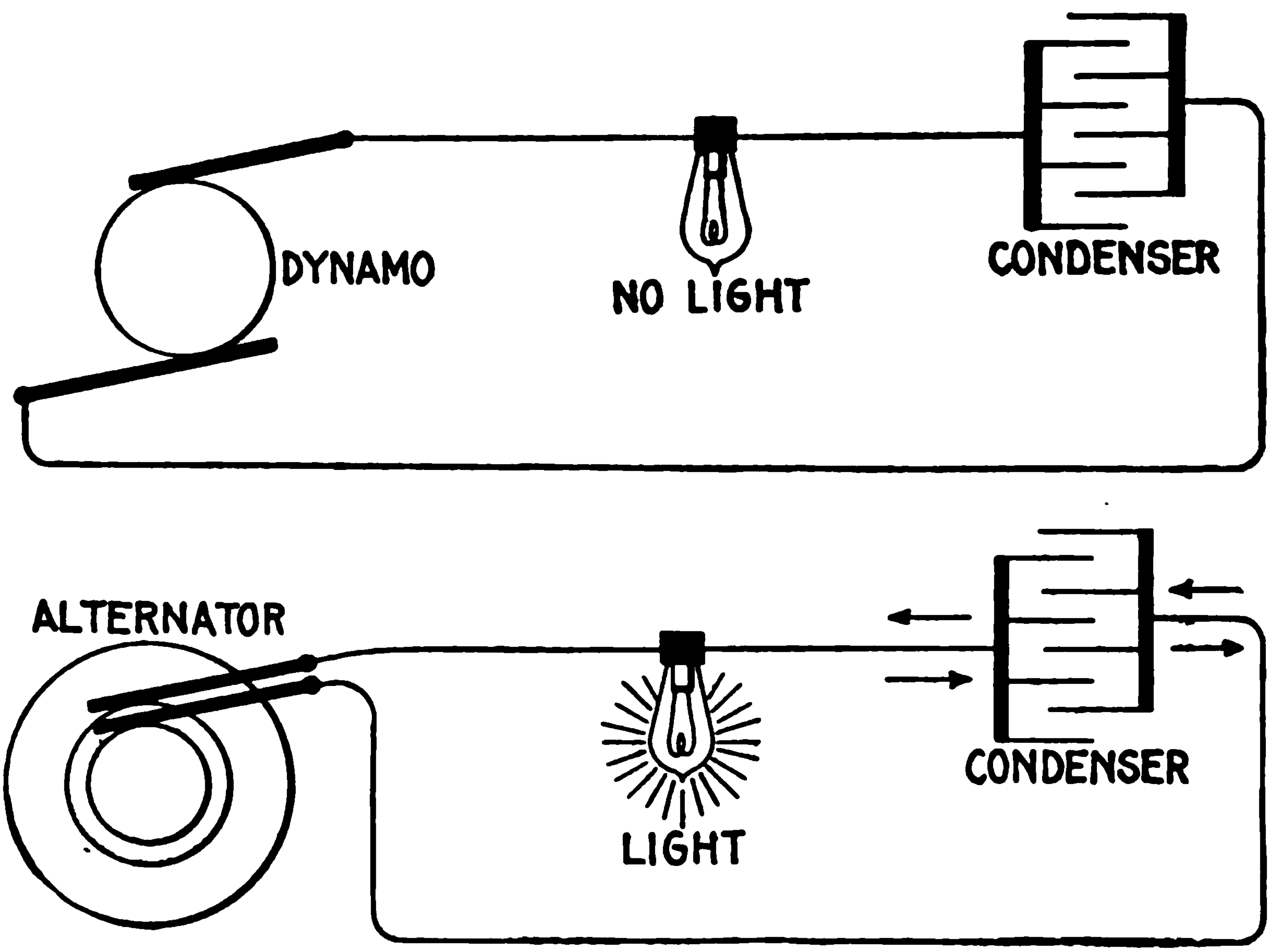
FIG. 1,284.—Series or cascade connection of condensers. Unlike terminals are joined together as shown. The total capacity of such connection is equal to *the reciprocal of the sum of the reciprocals of the several capacities*, that is, $C = 1 + \left(\frac{1}{c} + \frac{1}{c'} + \frac{1}{c''}\right)$

Ohmic Value of Capacity.—The capacity of an alternating current circuit is the measure of the amount of electricity held by it when its terminals are at unit difference of pressure. Every such circuit acts as a condenser.

If an alternating circuit, having no capacity, be opened, no current can be produced in it, but if there be capacity at the break, current may be produced as in fig. 1,286.

The action of capacity referred to the current wave is as follows: As the wave starts from zero value and rises to its maximum value, *the current is* due to the discharge of the

capacity, which would be represented by a condenser. In the case of a sine current, the period required for the current to pass from zero value to maximum is one-quarter of a cycle.



FIGS. 1,285 and 1,286.—Diagrams showing effect of condenser in direct and alternating current circuits. Each circuit contains an incandescent lamp and a condenser, one circuit connected to a dynamo and the other to an alternator. Since the condenser interposes a gap in the circuit, evidently in fig. 1,285 no current will flow. In the case of alternating current, fig. 1,286, the condenser gap does not hinder the flow of current in the metallic portion of the circuit. In fact the alternator produces a continual surging of electricity backwards and forwards from the plates of the condenser around the metallic portion of the circuit, similar to the surging of waves against a bulkhead which projects into the ocean. It should be understood that the electric current ceases at the condenser, there being no flow between the plates.

At the beginning of the cycle, the condenser is charged to the maximum amount it receives in the operation of the circuit.

At the end of the quarter cycle when the current is of maximum value, the condenser is completely discharged.

The condenser now begins to receive a charge, and continues to receive it during the next quarter of a cycle, the charge attaining its maximum value when the current is of zero intensity. Hence, the *maximum charge of a condenser* in an alternating circuit is equal to the average value of the current multiplied by the time of charge, which is one-quarter of a period, that is

$$\text{maximum charge} = \text{average current} \times \tfrac{1}{4} \text{ period} \ldots\ldots (1)$$

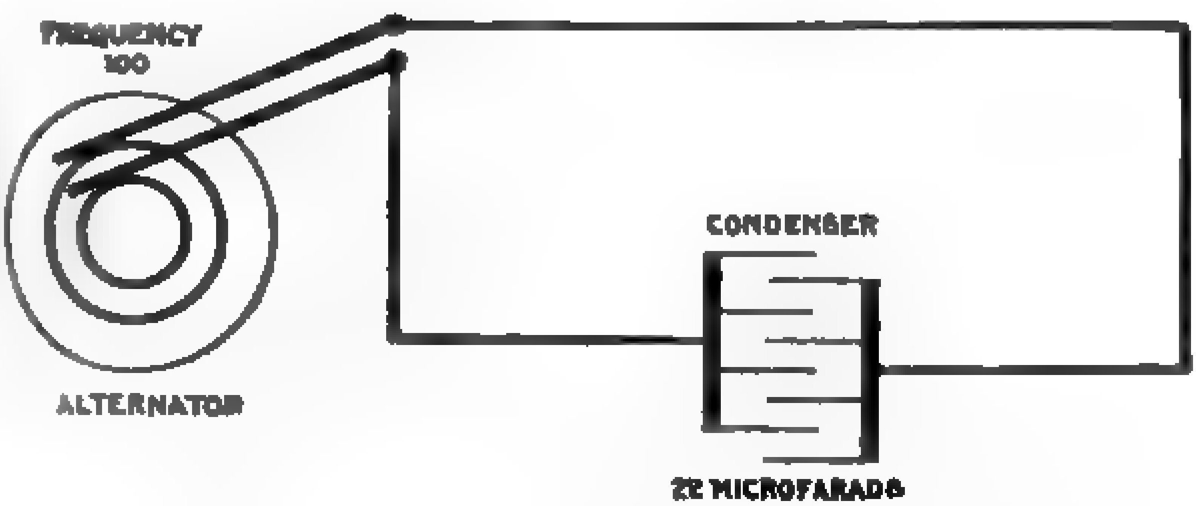


FIG. 1,287.—Diagram showing alternating circuit containing capacity. Formula for calculating the ohmic value of capacity or "capacity reactance" is $X_c = 1 \div 2\pi f C$, in which X_c = capacity reactance; $\pi = 3.1416$; f = frequency; C = capacity *in farads* (not microfarads). 22 microfarads = 22 ÷ 1,000,000 = .000022 farad. Substituting, $X_c = 1 \div (2 \times 3.1416 \times 100 \times .000022) = 72.4$ ohms.

Since the time of a period = 1 ÷ frequency, the time of one-quarter of a period is $\tfrac{1}{4} \times (1 \div \text{frequency})$, or

$$\tfrac{1}{4} \text{ period} = \tfrac{1}{4} f \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

f, being the symbol for frequency. Substituting (2) in (1)

$$\text{maximum charge} = I_{av} \times \tfrac{1}{4} f \ldots\ldots\ldots\ldots (3)$$

The pressure of a condenser is equal to the quotient of the charge divided by the capacity, that is

$$\text{condenser pressure} = \frac{\text{charge}}{\text{capacity}} \ldots\ldots\ldots\ldots (4)$$

Substituting (3) in (4)

$$\text{condenser pressure} = (I_{av} \times \frac{1}{4f}) \div C = \frac{I_{av}}{4fC} \ldots\ldots (5)$$

But, $I_{av} = I_{max} \times \frac{2}{\pi}$, and substituting this value of I_{av} in equation (5) gives

$$\text{condenser pressure} = \frac{I_{max} \times \frac{2}{\pi}}{4fC} = \frac{I_{max}}{2\pi fC} \ldots\ldots\ldots\ldots (6)$$

This last equation (6) represents the condenser pressure due to capacity at the point of maximum value, which pressure is opposed to the impressed pressure, that is, it is the maximum reverse pressure due to capacity.

Now, since by Ohm's law

$$I = \frac{E}{R}, \text{ or } E = I \times R$$

and as

$$\frac{I_{max}}{2\pi fC} = I_{max} \times \frac{1}{2\pi fC}$$

it follows that $\frac{1}{2\pi fC}$ is the *ohmic value* of capacity, that is it expresses the resistance equivalent of capacity; using the symbol X_c for capacity reactance

$$X_c = \frac{1}{2\pi fC} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

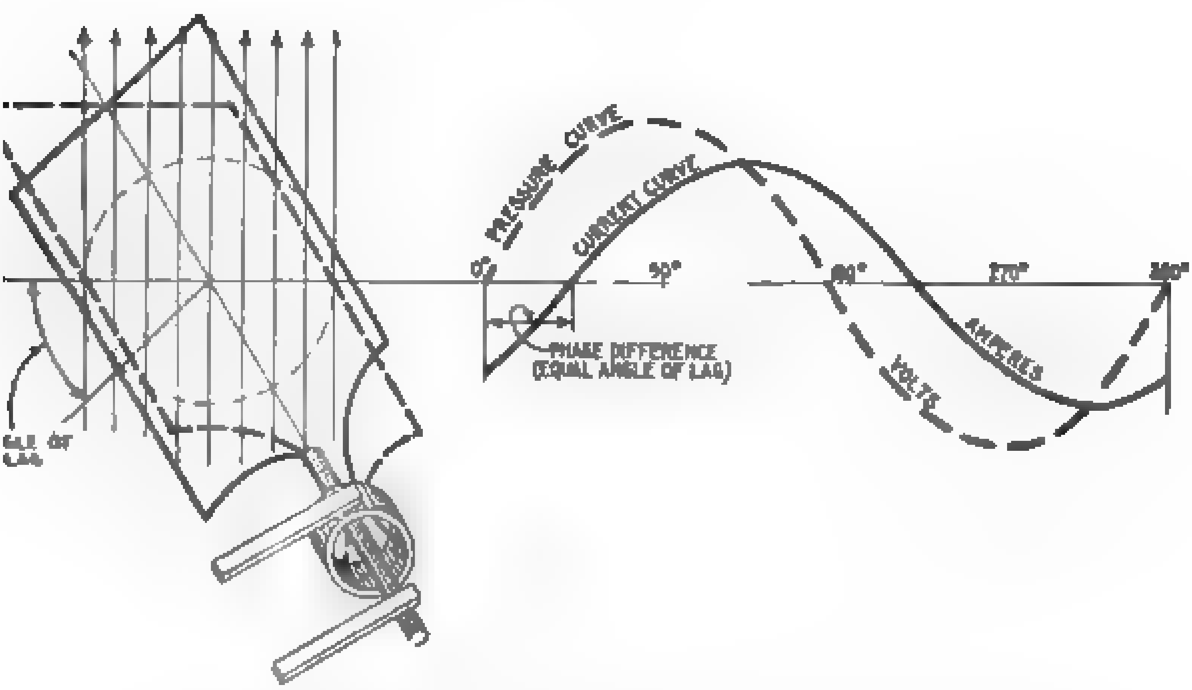
[redacted]

EXAMPLE.—What is the resistance equivalent of a 50 microfarad condenser to an alternating current having a frequency of 100?

Substituting the given values in the expression for ohmic value

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.1416 \times 100 \times .000050} = \frac{1}{.031416} = 31.8 \text{ ohms.}$$

If the pressure of the supply be, say 100 volts, the current would be $100 \div 31.8 = 3.14$ amperes.



ig. 1,288.—Pressure and current curves, illustrating *lag*. The effect of inductance in a circuit is to retard the current cycle, that is to say, if the current and pressure be in phase, the introduction of inductance will cause a phase difference, the current wave "lagging" behind the pressure wave as shown. In other words, inductance causes the current wave, indicated in the diagram by the solid curve, to lag behind the pressure wave, indicated by the dotted curve. Following the curves starting from the left end of the horizontal line, it will be noted that the current starts after the pressure starts and reverses after the pressure reverses; that is, ***the current lags in phase behind the pressure,*** although the frequency of both is the same.

Lag and Lead.—Alternating currents do not always keep in tep with the alternating volts impressed upon the circuit. If here be inductance in the circuit, the current will *lag;* if there e capacity, the current will *lead* in phase. For example, fig. ,288, illustrates the lag due to inductance and fig. 1,289, the ead due to capacity.

Ques. What is lag?

Ans. Lag denotes the condition where the phase of one alternating current quantity lags behind that of another. The term is generally used in connection with the effect of inductance in causing the current to lag behind the impressed pressure.

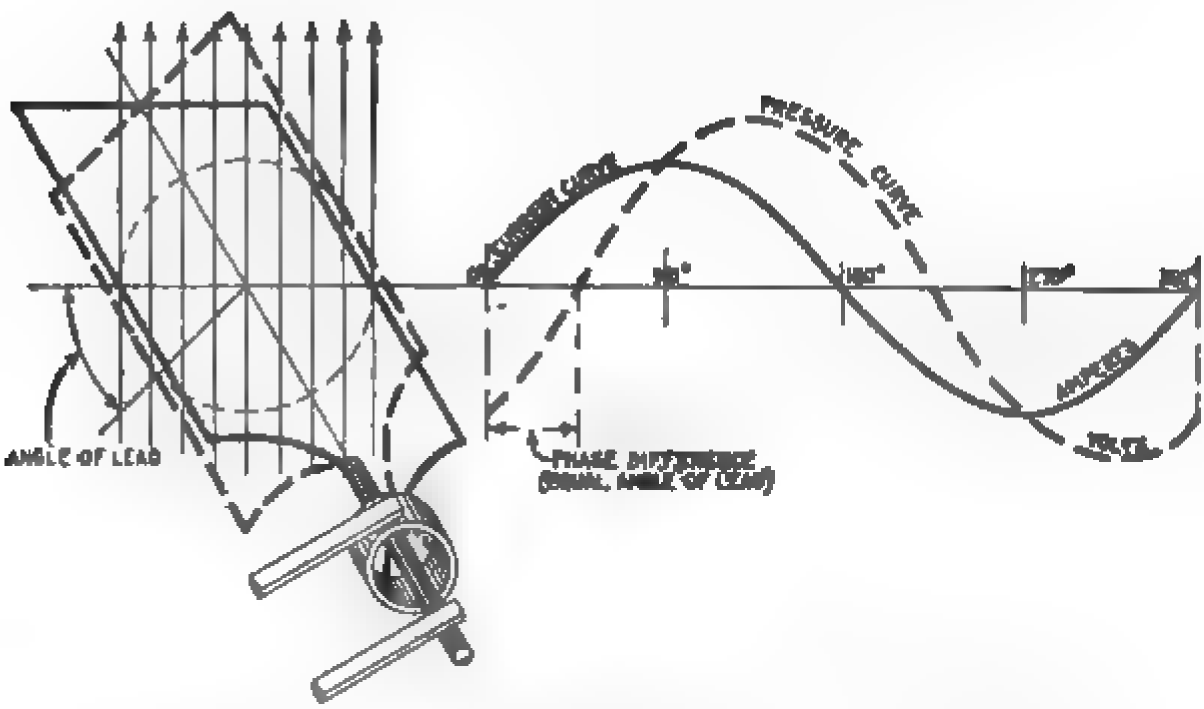


FIG. 1,289.—Pressure and current curves illustrating *lead.* The effect of capacity in a circuit is to cause the current to rise to its maximum value sooner than it would otherwise do; capacity produces an effect exactly the opposite of inductance. The phase relation between current and pressure with current leading is shown graphically by the two armature positions in full and dotted lines, corresponding respectively to current and pressure at the beginning of the cycle.

Ques. How does inductance cause the current to lag behind the pressure?

Ans. It tends to prevent changes in the strength of the current. When two parts of a circuit are near each other, so that one is in the magnetic field of the other, any change in the strength of the current causes a corresponding change in the magnetic field and sets up a reverse pressure in the other wire.

This induced pressure causes the current to reach its maximum value a little later than the pressure, and also tends to prevent the current *diminishing in step* with the pressure.

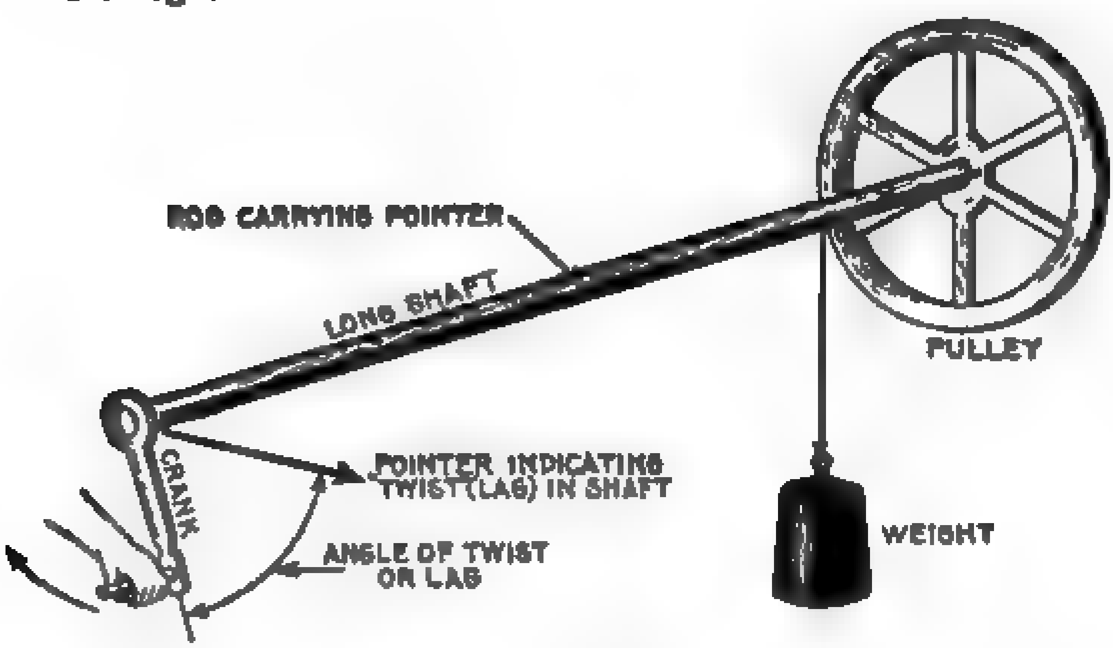
[redacted]

es. What governs the amount of lag in an alter-g current?

s. It depends on the relative values of the various pres- in the circuit, that is, upon the amount of resistance and tance which tends to cause lag, and the amount of capacity circuit which tends to reduce lag and cause lead.

es. How is lag measured?

. In degrees.



10.—Mechanical analogy of lag. If at one end force be applied to turn a very long t, having a loaded pulley at the other, the torsion thus produced in the shaft will e it to twist an appreciable amount which will cause the movement of the pulley to behind that of the crank. This may be indicated by a rod attached to the pulley terminating in a pointer at the crank end, the rod being so placed that the pointer ters with the crank when there is no torsion in the shaft. The angle made by the ter and crank when the load is thrown on, indicates the amount of lag which is sured in degrees.

Thus, in fig. 1,288, the lag is indicated by the distance between the eginning of the pressure curve and the beginning of the current curve, nd is in this case 45°.

es. What is the physical meaning of this?

. In an actual alternator, of which fig. 1,288 is an ele-ry diagram *showing one coil, if* the current lag, say 45°

behind the pressure, it means that the coil rotates 45° fro position of zero induction before the current starts, as in fig. 1

EXAMPLE I.—A circuit through which an alternating cur passing has an inductance of 6 ohms and a resistance of 2.5 ohms. is the angle of lag?

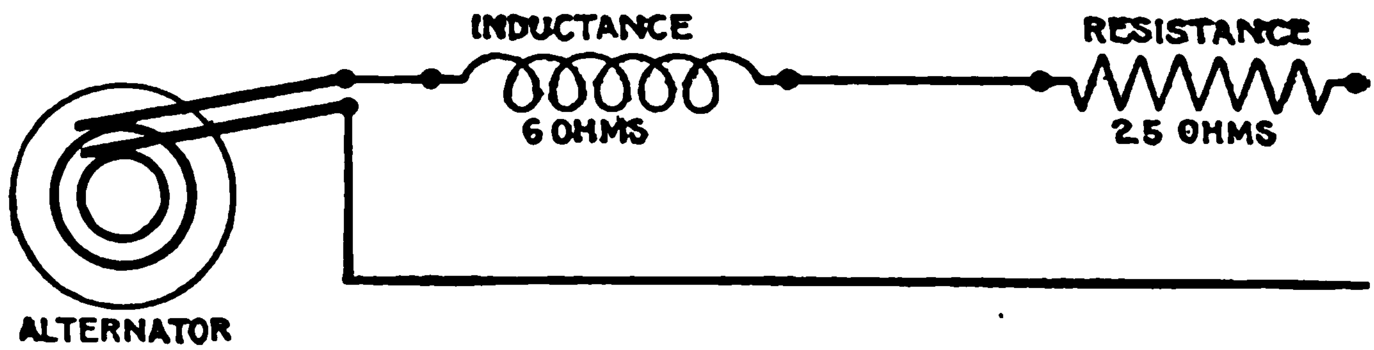


FIG. 1,291.—Diagram of circuit for example I.

Substituting these values in equation (1), page 1,053,

$$\tan \phi = \frac{6}{2.5} = 2.4$$

Referring to the table of natural sines and tangents on page 4 corresponding angle is approximately 67°.

EXAMPLE II.—A circuit has a resistance of 2.3 ohms and an i ance of .0034 henry. If an alternating current having a freque 125 pass through it, what is the angle of lag?

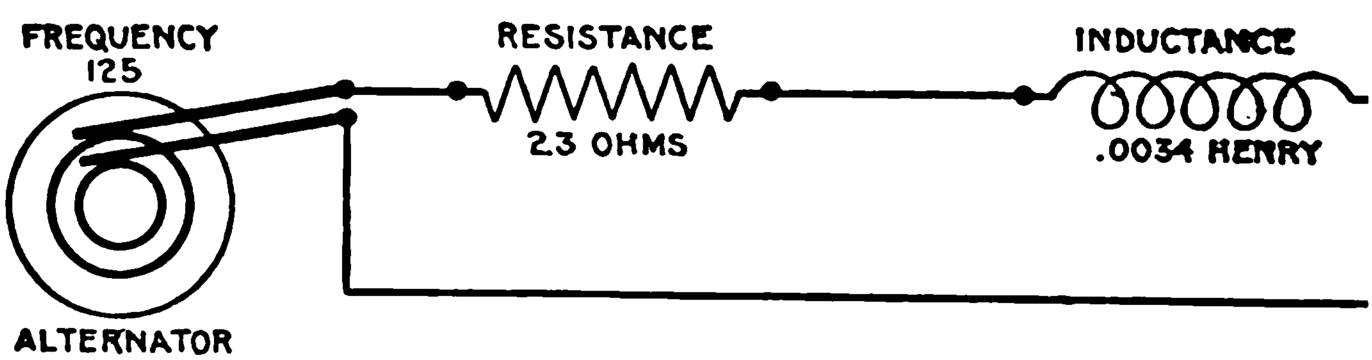


FIG. 1,292.—Diagram of circuit for example II.

Here the inductance is given as a fraction of a henry; this m reduced to ohms by substituting in equation (3), page 1,038, gives the ohmic value of the inductance; accordingly, substituti above given value in this equation

$$\text{inductance in ohms or } X_i = 2\pi \times 125 \times .0034 = 2.67$$

Substituting this result and the given resistance in equati page 1,053,

$$\tan \phi = \frac{2.67}{2.3} = 1.16$$

the nearest angle **from table (page 451) is 49°.**

Ques. How great may the angle of lag be?

Ans. Anything up to 90°.

The angle of lag, indicated by the Greek letter ϕ(phi), is the angle whose tangent is equal to the quotient of the inductance expressed in ohms or "spurious resistance" divided by the ohmic resistance, that is

$$\tan \phi = \frac{\text{reactance}}{\text{resistance}} = \frac{2\pi f L}{R} \quad \text{.....................(1)}$$

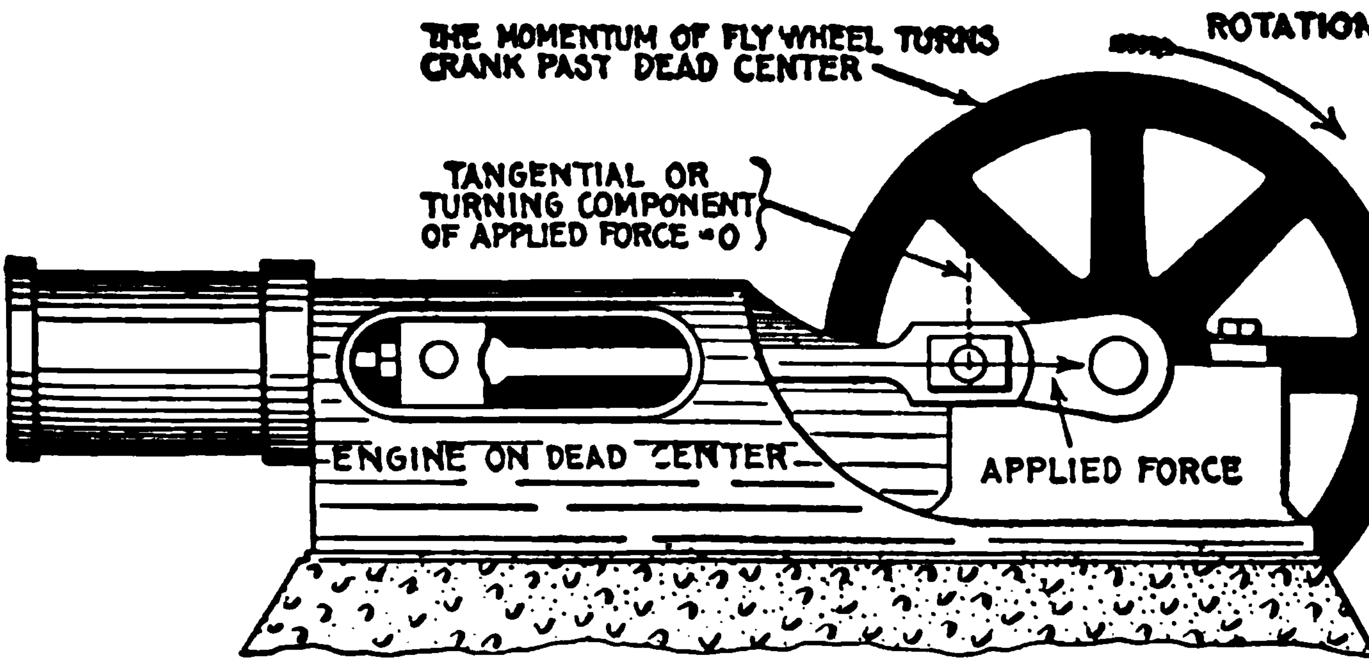


Fig. 1,293.—Steam engine analogy of current flow at zero pressure (see questions below). When the engine has reached the dead center point the full steam pressure is acting on the piston, the valve having opened an amount equal to its lead. The force applied at this instant, indicated by the arrow is perpendicular to the crank pin circle, that is, the tangential or *turning* component is equal to zero, hence there is no pressure tending to turn the crank. The latter continues in motion past the dead center because of the momentum previously acquired. Similarly, the electric current, which is here analogous to the moving crank, continues in motion, though the pressure at some instants be zero, because it acts as though it had weight, that is, it cannot be stopped or started instantly.

Ques. When an alternating current lags behind the pressure, is there not a considerable current at times when the pressure is zero?

Ans. Yes; such effect is illustrated by analogy in fig. 1,293.

Ques. What is the significance of this?

Ans. It does not mean that current could be obtained from a circuit *that showed no pressure* when tested with a suitable *voltmeter, for no current would flow* under such conditions. *However, in the flow of an alternating* current, the pressure

varies from zero to maximum values many times each second, and the instants of no pressure may be compared to the " dead centers " of an engine at which points there is no pressure to cause rotation of the crank, the crank being carried past these points by the momentum of the fly wheel. Similarly the electric current does not stop at the instant of no pressure because of the " momentum " acquired at other parts of the cycle.

Ques. On long lines having considerable inductance, how may the lag be reduced?

Ans. By introducing capacity into the circuit. In fact, the current may be advanced so it will be in phase with the pressure or even lead the latter, depending on the amount of capacity introduced.

There has been some objection to the term *lead* as used in describing the effect of capacity in an alternating circuit, principally on the ground that such expressions as " lead of current," " lead in phase," etc., tend to convey the idea that the effect precedes the cause, that is, the current is in advance of the pressure producing it. There can, of course, be no current until pressure has been applied, but if the circuit have capacity, it will lead the pressure, and this peculiar behavior is best illustrated by a mechanical analogy as has already been given.

Ques. What effect has lag or lead on the value of the effective current?

Ans. As the angle of lag or lead increases, the value of the effective as compared with the virtual current diminishes.

Reactance.—The term "reactance" means simply *reaction*. It is used to express certain effects of the alternating current other than that due to the ohmic resistance of the circuit. *Thus, inductance reactance* means the reaction due to the spuriou[s] *resistance of inductance* expressed in ohms; similarly, capaci[ty] *reactance*, means the reaction due to capacity, expressed in ohms.

It should be noted that the term *reactance*, alone, that is, unqualified, is generally understood to mean *inductance reactance*, though ill advisedly so.

The resistance offered by a wire to the flow of a direct current is expressed in ohms; this resistance remains constant whether the wire be straight or coiled. If an alternating current flow through the wire, there is in addition to the ordinary or "*ohmic*" resistance of the wire, a "*spurious*" resistance arising from the development of a reverse pressure due to induction, which is

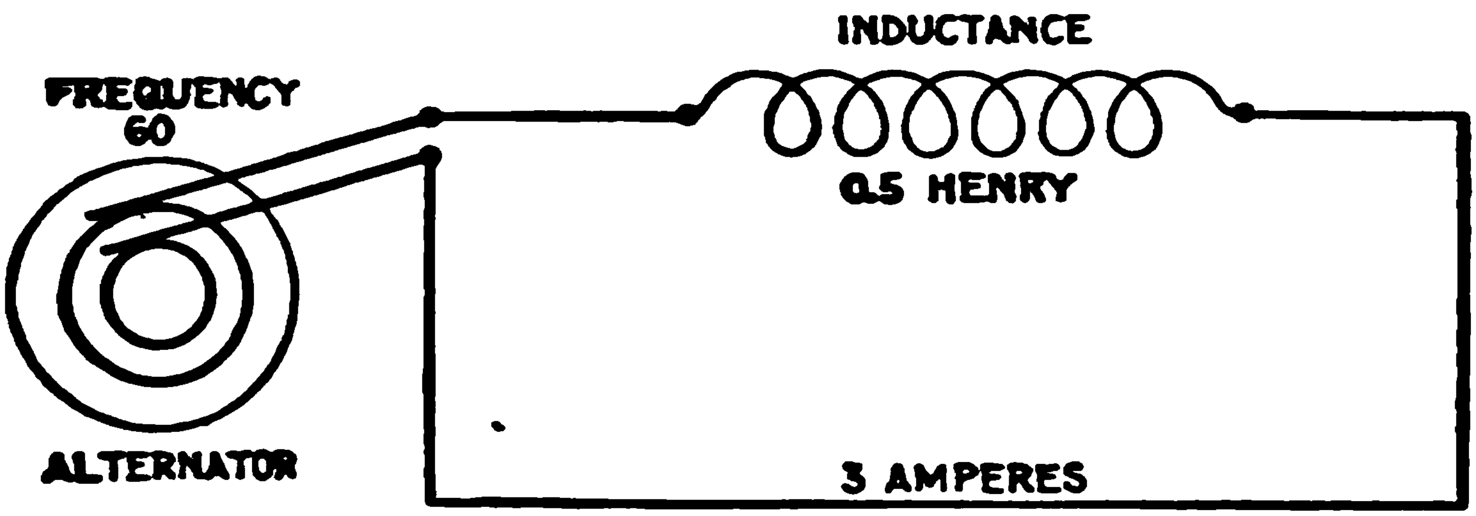


FIG. 1,294—Diagram of the circuit for example I. Here the resistance is taken at zero, but this would not be possible in practice, as all circuits contain more or less resistance though it may be, in some cases, negligibly small.

more or less in value according as the wire be coiled or straight. *This spurious resistance as distinguished from the ohmic resistance is called the reactance, and is expressed in ohms.*

Reactance, may then be defined with respect to its usual significance, that is, *inductance reactance*, as *the component of the impedance which when multiplied into the current, gives the wattless component of the pressure.*

Reactance is simply inductance measured in ohms.

EXAMPLE I.—An alternating current having a frequency of 60 is passed through a coil whose inductance is .5 henry. What is the reactance?

Here f = 60 and L = .5; substituting these in formula for inductive reactance,

$$X_i = 2\pi f L = 2 \times 3.1416 \times 60 \times .5 = 188.5 \text{ ohms}$$

The quantity $2\pi f L$ or reactance being of the same nature as a resistance is used in the same way as a resistance. Accordingly, since, by Ohm's law

$$E = R I \qquad \text{(1)}$$

an expression may be obtained for the volts necessary to overcome reactance by substituting in equation (1) the value of reactance given above, thus

$$E = 2\pi f L I \qquad \text{(2)}$$

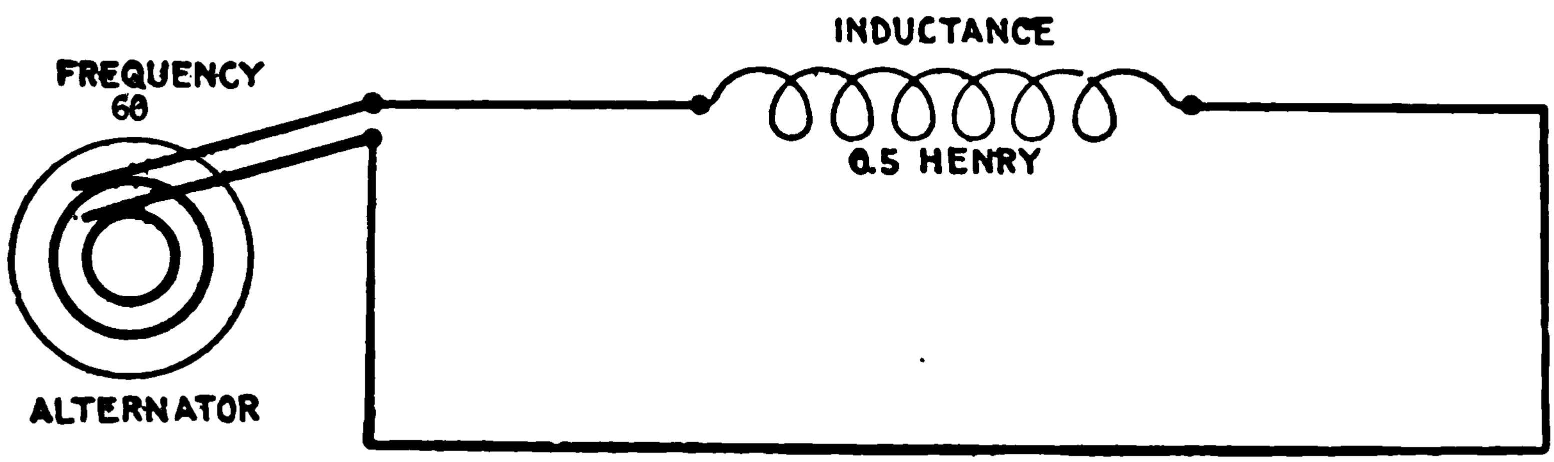


Fig. 1,295.—Diagram of circuit for example II. As in example I, resistance is disregarded.

EXAMPLE II.—How many volts are necessary to force a current of 3 amperes with frequency 60 through a coil whose inductance is .5 henry? Substituting in equation (2) the values here given

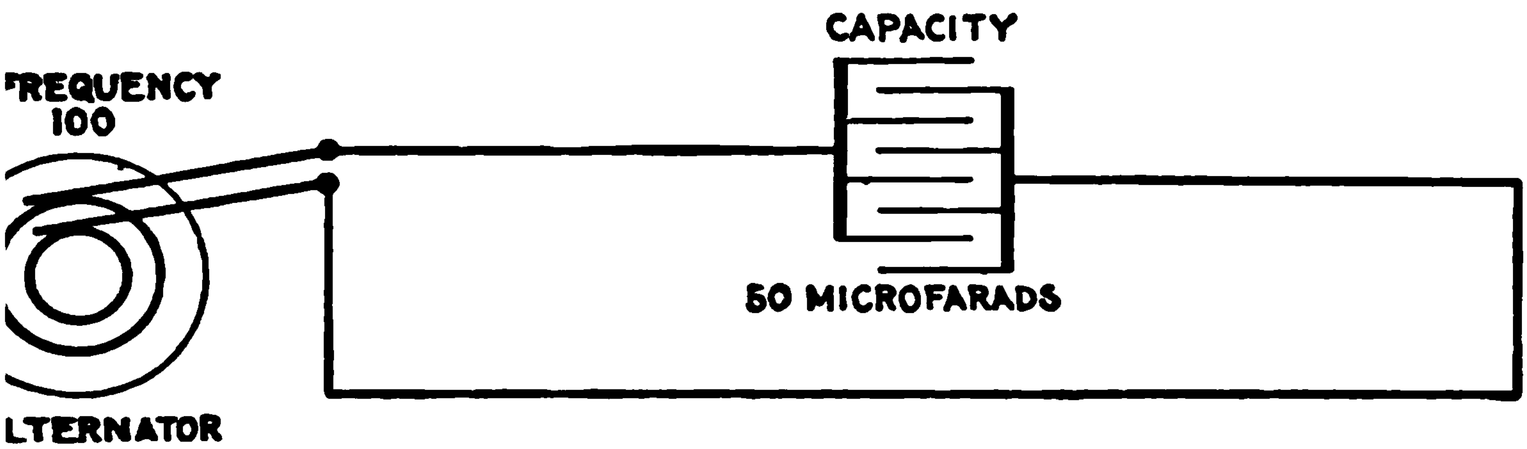
$$E = 2\pi f L I = 2\pi \times 60 \times .5 \times 3 = 565 \text{ volts.}$$

The foregoing example may serve to illustrate the difference in behaviour of direct and alternating currents. As calculated, it requires 565 volts to pass only 3 amperes of alternating current through the coil on account of the considerable spurious resistance. The ohmic resistance of a coil is very small, as compared with the spurious resistance, say 2 ohms. Then by Ohm's law $I = E \div R = 565 \div 2 = 282.5$ amperes.

Instances of this effect are commonly met with in connection with transformers. Since the primary coil of a transformer has a high reactance, very little current will flow when an alternating pressure is *applied. If the same* transformer were placed in a direct current circuit

[redacted]

and the current turned on it would at once burn out, as very little resistance would be offered and a large current would pass through the winding.



:. 1,296.—Diagram of circuit for example III.

EXAMPLE III.—In a circuit containing only capacity, what is the reactance when current is supplied at a frequency of 100, and the capacity is 50 microfarads?

$$50 \text{ microfarads} = 50 \times \frac{1}{1{,}000{,}000} = .00005 \text{ farad}$$

pacity reactance, or

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2 \times 3.1416 \times 100 \times .00005} = 31.84 \text{ ohms}$$

Impedance.—This term, strictly speaking, means the *ratio ' any impressed pressure to the current which it produces in a nductor.* It may be further defined as *the total opposition in n electric circuit to the flow of an alternating current.*

All power circuits for alternating current are calculated with ference to impedance. The impedance may be called the mbination of:

1. Ohmic resistance;
2. Inductance reactance;
3. Capacity reactance.

The impedance of an inductive circuit which does not contain capacity is equal to *the square root of the sum of the squares of the resistance and reactance*, that is

$$impedance = \sqrt{resistance^2 + reactance^2} \quad \ldots\ldots\ldots(1)$$

EXAMPLE I.—If an alternating pressure of 100 volts be impressed on a coil of wire having a resistance of 6 ohms and inductance of 8 ohms, what is the impedance of the circuit and how many amperes will flow through the coil? In the example here given, 6 ohms is the resistance and 8 ohms the reactance. Substituting these in equation (1)

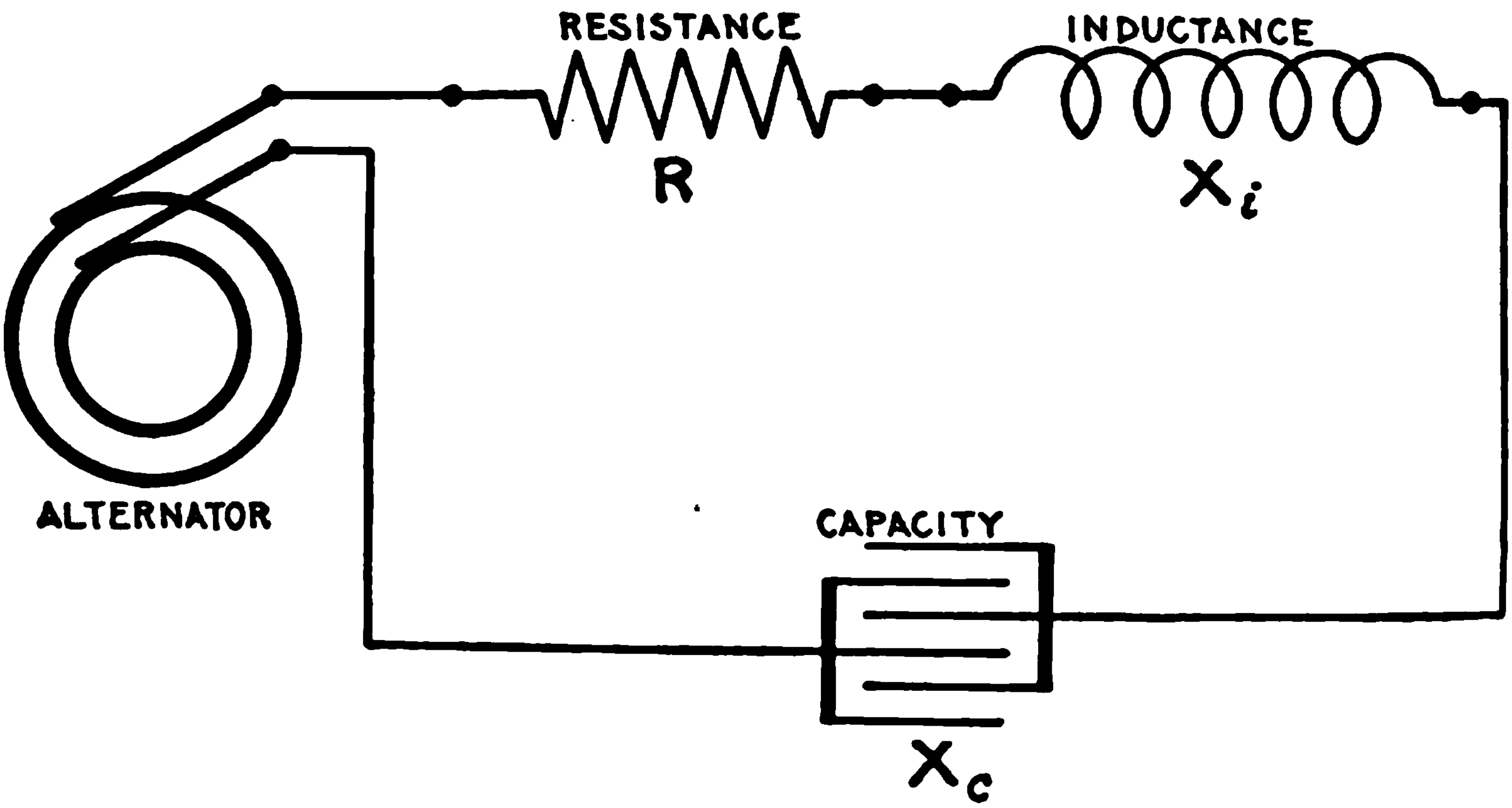


FIG. 1,297.—Diagram showing alternating circuit containing resistance, inductance, and capacity. Formula for calculating the impedance of this circuit is $Z = \sqrt{R^2 + (X_l - X_c)}$ in which, Z = impedance; R = resistance; X_l = inductance reactance; X_c = capacity reactance. Example: What is the impedence when R = 4, X_l = 92.4, and X_c = 72.4? Substituting $Z = \sqrt{4^2 + (94.2 - 72.4)^2} = 22.2$ ohms. Where the ohmic values of inductance and capacity are given as in this example, the calculation of impedance is very simple, but when inductance and capacity are given in milli-henrys and microfarads respectively, it is necessary to first calculate their ohmic values as in figs. 1,295 and 1,296.

$$\text{Impedance} = \sqrt{6^2 + 8^2} = \sqrt{100} = 10 \text{ ohms.}$$

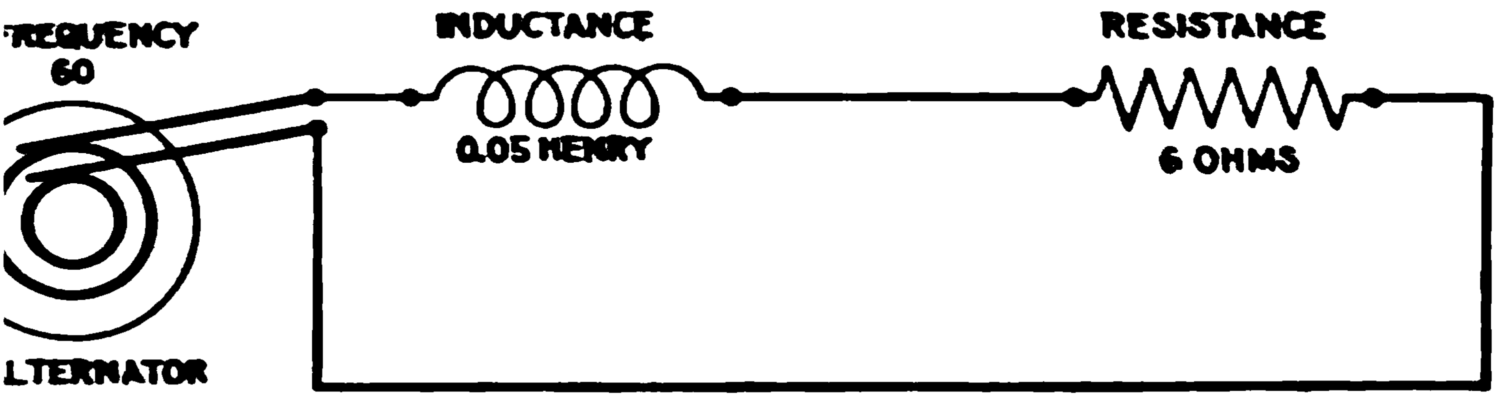
The current in amperes which will flow through the coil is, by Ohm's law using impedance in the same way as resistance.

$$\text{current} = \frac{\text{volts}}{\text{impedance}} = \frac{100 \text{ volts}}{10 \text{ ohms}} = 10 \text{ amperes.}$$

[redacted]

The reactance is not always given but instead in some problems the frequency of the current and inductance of the circuit. An expression to fit such cases is obtained by substituting $2\pi fL$ for the reactance as follows: (using symbols for impedance and resistance)

$$Z = \sqrt{R^2 + (2\pi fL)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

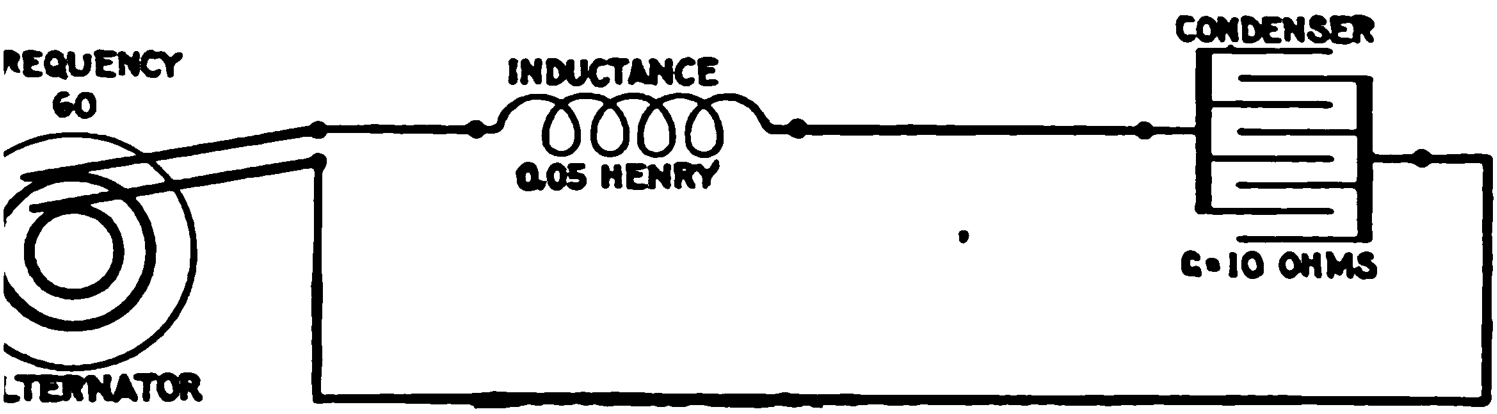


. 1,298.—Diagram of circuit for example II.

EXAMPLE II.—If an alternating current, having a frequency of 60, be impressed on a coil whose inductance is .05 henry and whose resistance is 6 ohms, what is the impedance?

Here R = 6; f = 60, and L = .05; substituting these values in (2)

$$Z = \sqrt{6^2 + (2\pi \times 60 \times .05)^2} = \sqrt{393} = 19.8 \text{ ohms.}$$



. 1,299.—Diagram of circuit for example III.

EXAMPLE III.—If an alternating current, having a frequency of 60, be impressed on a circuit whose inductance is .05 henry, and whose capacity reactance is 10 ohms, what is the impedance?

$$X_l = 2\pi fL = 2 \times 3.1416 \times 60 \times .05 = 18.85 \text{ ohms}$$

$$Z = X_l - X_c = 18.85 - 10 = 8.85 \text{ ohms}$$

When a circuit contains besides resistance, ***both inductance and capacity***, the formula for impedance as given in equation (1), page 1,058, must be modified to include the reactance due to capacity, because, as explained, inductive and capacity reactances work in opposition to each other, in the sense that the reactance of inductance acts in direct proportion to the quantity $2\pi f L$, and the reactance of capacity in inverse proportion to the quantity $2\pi f C$. The net reactance due to both, when both are in the circuit, is obtained by subtracting one from the other.

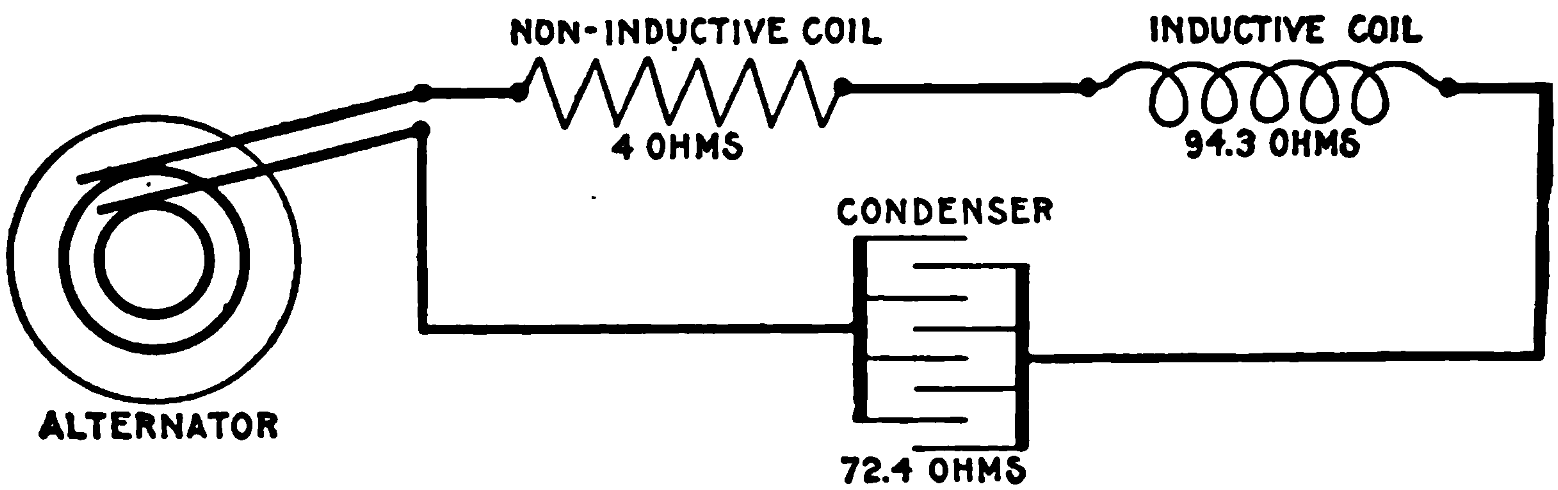


Fig. 1,300.—Diagram of circuit for example IV.

To properly estimate impedance then, in such circuits, the following equation is used:

$$\textit{impedance} = \sqrt{\textit{resistance}^2 + (\textit{inductance reactance} - \textit{capacity reactance})^2}$$

or using symbols,

$$Z = \sqrt{R^2 + (X_i - X_c)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

EXAMPLE IV.—A current has a frequency of 100. It passes through a circuit of 4 ohms resistance, of 150 milli-henrys inductance, and of 22 microfarads capacity. What is the impedance?

a. The ohmic resistance R, is 4 ohms.

b. The inductance reactance, or

$$X_i = 2\pi f L = 2 \times 3.1416 \times 100 \times .15 = 94.3 \text{ ohms.}$$

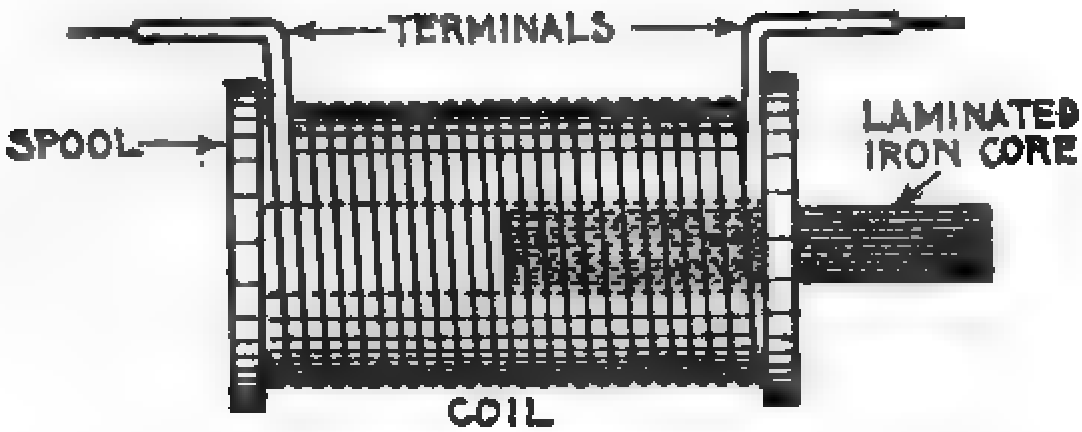


FIG. 1,301.—Simple choking coil. There is an important difference in the obstruction offered to an alternating current by ordinary resistance and by reactance. Resistance obstructs the current by dissipating its energy, which is converted into heat. Reactance obstructs the current by setting up a reverse pressure, and so reduces the current in the circuit, *without wasting much energy*, except by hysteresis in any iron magnetised. This may be regarded as one of the advantages of alternating over direct current, for, by introducing reactance into a circuit, the current may be cut down with comparatively little loss of energy. This is generally done by increasing the inductance in a circuit, by means of a device called variously a *reactance coil, impedance coil, choking coil*, or "*choker*." In the figure is a coil of thick wire provided with a laminated iron core, which may be either fixed or movable. In the first case, the inductance, and therefore also the reactance of the coil, is invariable, with a given frequency. In the second case, the inductance and consequent reactance may be respectively increased or diminished by inserting the core farther within the coil or by withdrawing it, as was done in fig. 1,300, the results of which are shown in fig. 1,302.

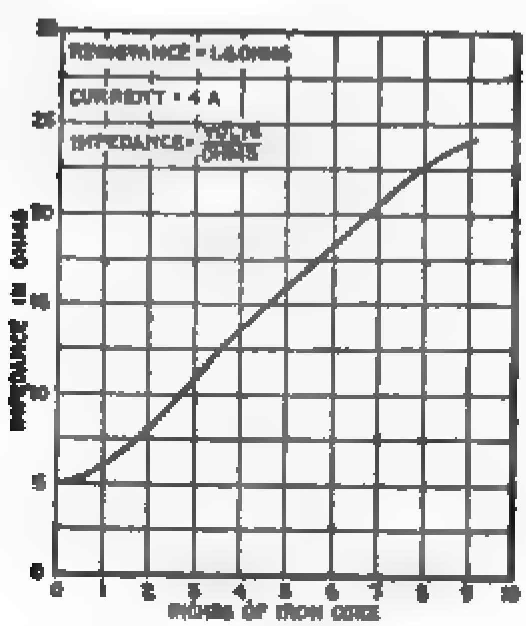


FIG. 1,302.—Impedance curve for coil with variable iron core. The impedance of an inductive coil may be increased by moving an iron wire core into the coil. In making a test of this kind, the current should be kept constant with an adjustable resistance, and voltmeter readings taken, first without the iron core, and again with 1, 2, 3, 4, etc., inches of core inserted in the coil. By plotting the voltmeter readings and the positions of the iron core on section paper as above, *the effect of inductance* is clearly shown.

(note that 150 milli-henrys are reduced to .15 henry before substituting in the above equation).

c. The capacity reactance, or

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.1416 \times 100 \times .000022} = 72.4 \text{ ohms}$$

(note that 22 microfarads are reduced to .000022 farad before substituting in the formula. Why? See page 1,042).

Substituting values as calculated in equation (3), page 1,060.

$$Z = \sqrt{4^2 + (94.2 - 72.4)^2} = \sqrt{491} = 22.2 \text{ ohms.}$$

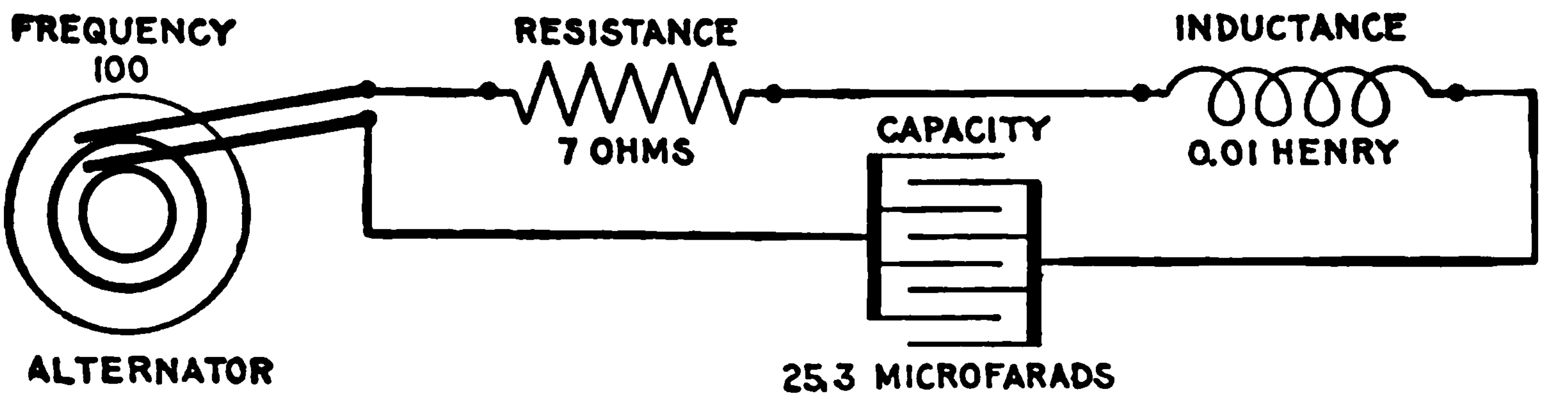


FIG. 1,303.—Diagram of a resonant circuit. A circuit is said to be resonant when the inductance and capacity are in such proportion that the one neutralizes the other, the circuit then acting as though it contained only resistance. In the above circuit $X_l = 2\pi f L = 2 \times 3.1416 \times 100 \times .01 = 6.28$ ohms; $X_c = 1 \div (2 \times 3.1416 \times 100 \times .000253) = 6.28$ ohms whence the resultant reactance $= X_l - X_c = 6.28 - 6.28 = 0$ ohms. $Z = \sqrt{R^2 + (X_l - X_c)^2} = \sqrt{7^2 + 0^2} = 7$ ohms.

Ques. Why is capacity reactance given a negative sign?

Ans. Because it reacts in opposition to inductance, that is it tends to reduce the spurious resistance due to inductance.

In circuits having both inductance and capacity, the tangent of the angle of lag or lead as the case may be is the algebraic sum of the two reactances divided by resistance. If the sign be positive, it is an angle of lag; if negative, of lead.

Resonance.—The effects of inductance and capacity, as already explained, oppose each other. If inductance and capacity be present in a circuit in such proportion that the effect of one neutralizes that of the other, the circuit acts as though it were purely non-inductive and is said to be in a state of *resonance*.

For instance, in a circuit containing resistance, inductance, and capacity, if the resistance be, say, 8 ohms, the inductance 30, and the capacity 30, then the impedance is

$$\sqrt{8^2 + (30^2 - 30^2)} = \sqrt{8^2} = 8 \text{ ohms.}$$

The formula for inductance reactance is $X_i = 2\pi f L$, and for capacity reactance, $X_c = 1 \div (2\pi f C)$; accordingly if capacity

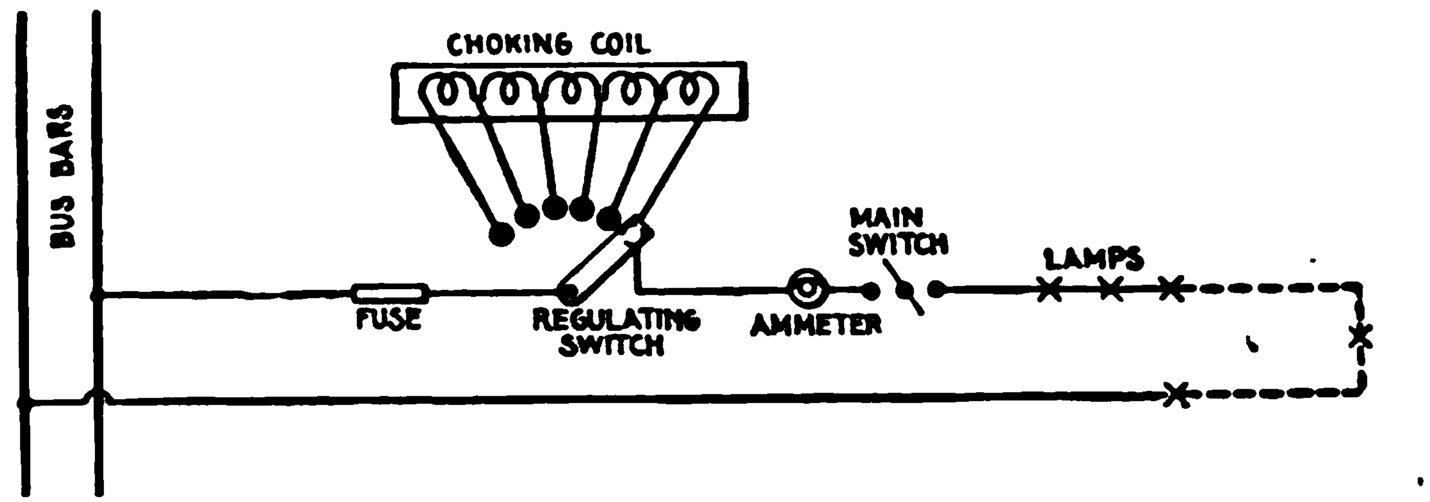


Fig. 1,304.—Application of a choking coil to a lighting circuit. The coil is divided into sections with leads running to contacts similar to a rheostat. Each lamp is provided with an automatic short-circuiting cutout, and should one, two, or more of them fail, a corresponding number of sections of the choking apparatus is put in circuit to take the place of the broken lamp or lamps, and thus keep the current constant. It must not be supposed that this arrangement of lamps, etc. is a general one; it being adopted to suit certain special conditions.

and inductance in a circuit be equal, that is, if the circuit be resonant

$$2\pi f L = \frac{1}{2\pi f C} \quad \text{..................(1)}$$

from which

$$f = \frac{1}{2\pi \sqrt{CL}} \quad \text{..................(2)}$$

Ques. What does equation (1) show?

Ans. It indicates that by varying the frequency in the proper way as by increasing or decreasing the speed of the alternator, the circuit may be made resonant, this condition being obtained when the *frequency has the* value indicated by equation (2).

[redacted]

Ques. What is the mutual effect of inductance and capacity?

Ans. One tends to neutralize the other.

Ques. What effect has resonance on the current?

Ans. It brings the current in phase with the impressed pressure.

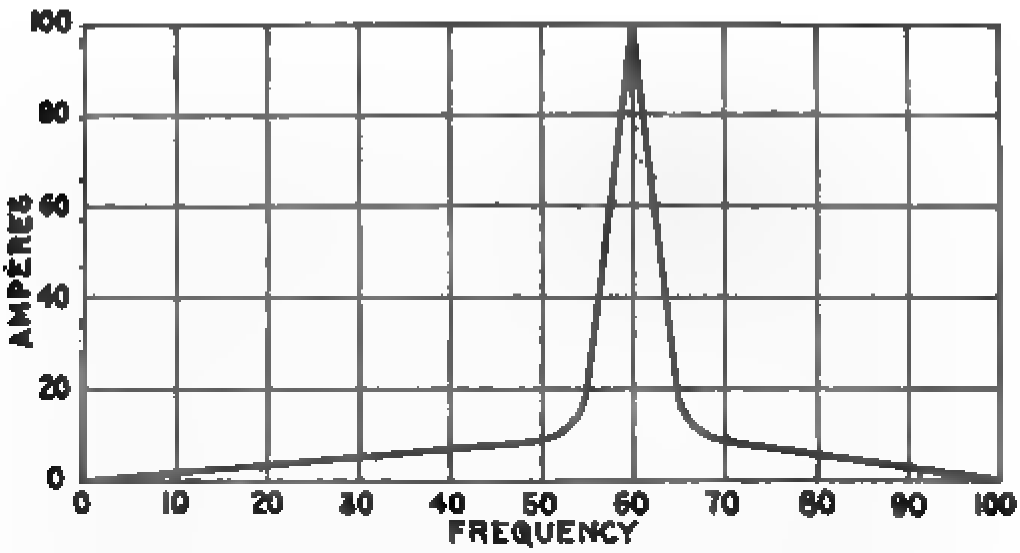


FIG. 1,305.—Curve showing variation of current by increasing the frequency in a circuit having inductance and capacity. The curve serves to illustrate the "critical frequency" or frequency producing the maximum current. The curve is obtained by plotting current values corresponding to different frequencies, the pressure being kept constant.

It is very seldom that a circuit is thus balanced unless intentionally brought about; when this condition exists, the effect is very marked, the pressure rising excessively and bringing great strain upon the insulation of the circuit.

Ques. Define "critical frequency."

Ans. In bringing a circuit to a state of resonance by increasing the frequency, the current will increase with *increasing frequency* until the critical frequency is reached, and then the *current will decrease* in value for further increase of frequency. *The critical frequency* occurs when the circuit reaches the *condition of resonance.*

[redacted]

Ques. How is the value of the current at the critical frequency determined?

Ans. By the resistance of the circuit.

Skin Effect.—This is the tendency of alternating currents to avoid the central portions of solid conductors and to flow or pass mostly through the outer portions. The so-called skin effect becomes more pronounced as the frequency is increased.

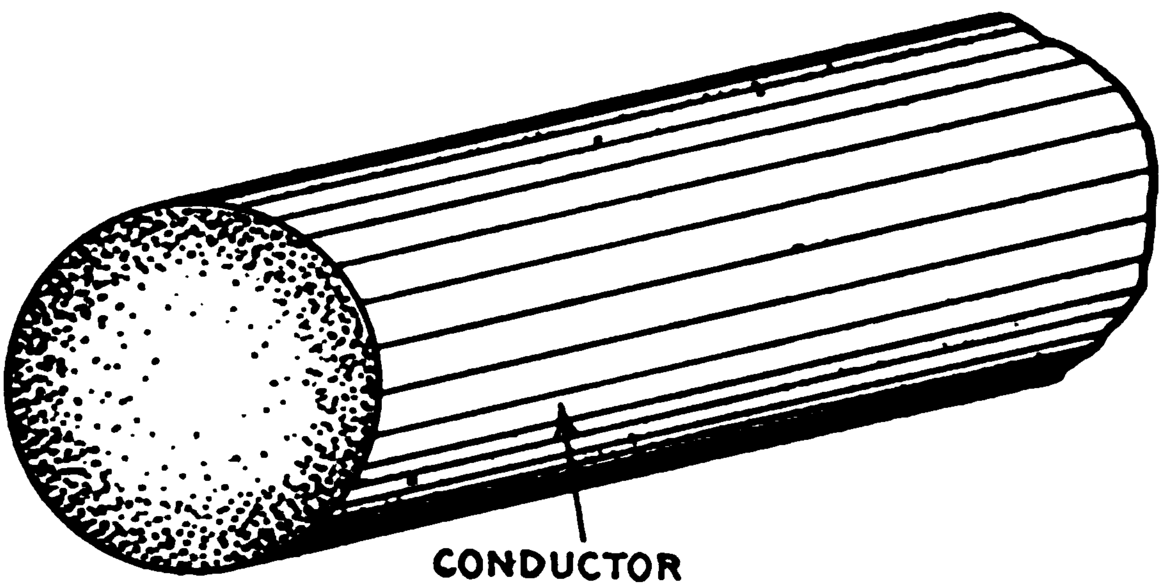


FIG. 1,306.—Section of conductor illustrating "skin effect" or tendency of the alternating current to distribute itself unequally through the cross section of the conductor as shown by the varied shading flowing most strongly in the outer portions of the conductor. For this reason it has been proposed to use hollow or flat conductors instead of solid round wires. However with frequency not exceeding 100 the skin effect is negligibly small in copper conductors of the sizes usually employed. Where the conductor is large or the frequency high the effect may be judged by the following examples calculated by Professor J. J. Thomson: In the case of a copper conductor exposed to an electromotive force making 100 periods per second at 1 centimetre from the surface, the maximum current would be only .208 times that at the surface; at a depth of 2 centimetres it would be only .043; and at a depth of 4 centimetres less than .002 part of the value at the surface. If the frequency be a million per second the current at a depth of 1 millimetre is less than one six-millionth part of its surface value. The case of an iron conductor is even more remarkable. Taking the permeability at 100 and the frequency at 100 per second the current at a depth of 1 millimetre is only .13 times the surface value; while at a depth of 5 millimetres it is less than one twenty-thousandth part of its surface value. The disturbance of current density may be looked upon as a self-induced eddy current in the conductor. It necessarily results in an increase of ohmic loss; as compared with a steady current: proportional to the square of the total current flowing and consequently gives rise to an apparent increase of ohmic resistance. The coefficient of increase of resistance depends upon the dimensions and the shape of the cross section, the frequency and the specific resistance. A similar but distinct effect is experienced in conductors due to the neighborhood of similar parallel currents. For example in a heavy multicore cable the non-uniformity of current density in any core may be considered as partly due to eddy currents induced by the currents in the neighboring cores and partly to the self-induced eddy current. It is only the latter effect which should rightly be considered as comprised under the term *skin effect.*

Ques. What is the explanation of skin effect?

Ans. It is due to eddy currents induced in the conductor.

Consider the wire as being composed of several small insulated wires placed closely together. Now when a current is started along these separate wires, mutual induction will take place between them, giving rise to momentary reverse pressures. Those wires which are nearer the center, since they are completely surrounded by neighboring wires, will clearly have stronger reverse pressures set up in them than those on or near the outer surface, so that the current will meet less opposition near the surface than at the center, and consequently the flow will be greater in the outer portions.

Ques. What is the result of skin effect?

Ans. It results in an apparent increase of resistance.

The coefficient of increase of resistance depends upon the dimensions and the shape of the cross section, the frequency, and the specific resistance.

Hughes, about 1883, called attention to the fact that the resistance of an iron telegraph wire was greater for rapid periodic currents than for steady currents.

In 1888 Kelvin showed that when alternating currents at moderately high frequency flow through massive conductors, the current is practically confined to the skin, the interior portions being largely useless for the purpose of conduction. The mathematical theory of the subject has been developed by Kelvin, Heaviside, Rayleigh, and others.

CHAPTER XLVII

ALTERNATING CURRENT DIAGRAMS

Whenever an alternating pressure is impressed on a circuit, part of it is spent in overcoming the resistance, and the rest goes to balance the reverse pressure due to self-induction.

The total pressure applied to the circuit is known as the *impressed pressure*, as distinguished from that portion of it called the *active pressure* which is used to overcome the resistance, and that portion called the *self-induction pressure* used to balance the reverse pressure of self-induction.

The intensity of the reverse pressure induced in a circuit due to self-induction is proportional to the *rate of change in the current strength.*

Thus a current, changing at the rate of one ampere per second, in flowing through a coil having a coefficient of self-induction of one henry, will induce a reverse pressure of one volt.

Ques. Describe how the rate of change in current strength varies, and how this affects the reverse pressure.

Ans. The alternating current varies from zero to maximum strength in one-quarter period, that is, in one-quarter revolution of the generating loop or 90° as represented by the sine curve in fig. 1,307. Now, during, say, the first 10 degrees of rotation (from 0 to *A*), *the current* jumps from zero value to A', or 4

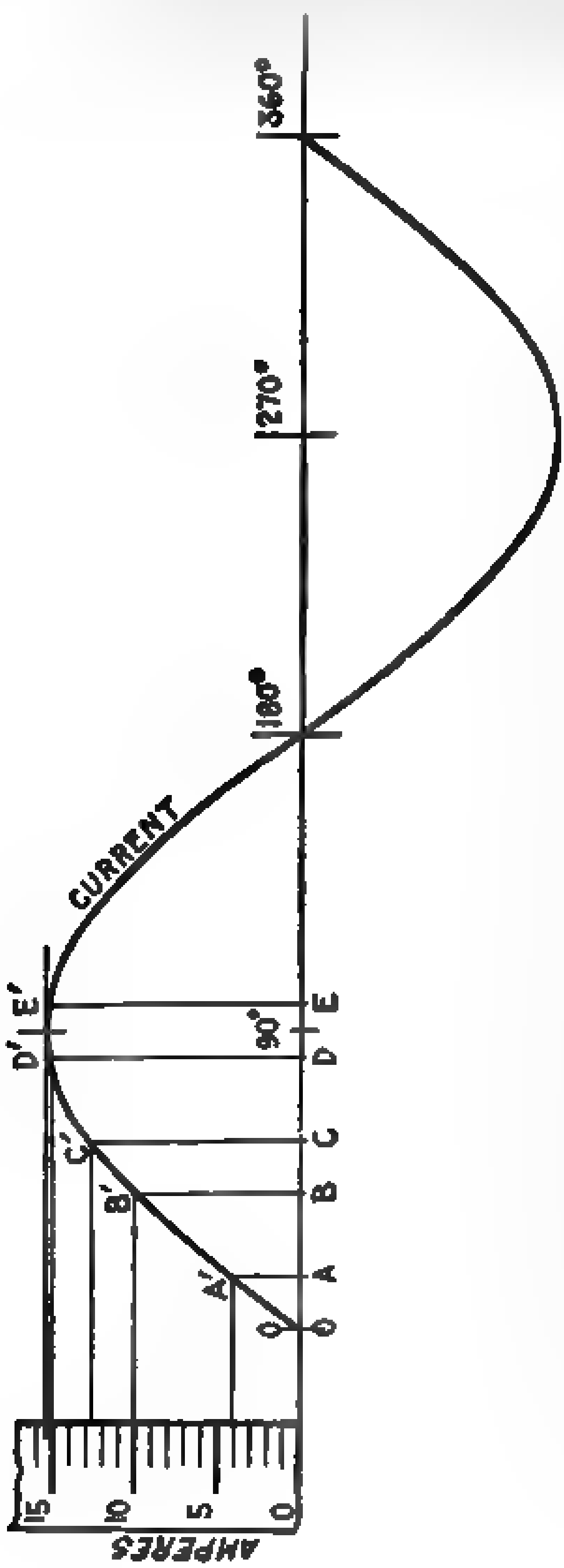


Fig. 1,307.—Sine curve showing that the *rate of change* in the strength of an alternating current *is greatest when the current is least, and zero when the current is at a maximum.* This is evident from the diagram, since during say the first 10° as OA, the current increases 4 amperes; during BC, 2½ amperes; during DE it rises and falls ½ ampere. The reverse pressure of self-induction being proportional to the *rate of change* of the current, is a maximum when the current is zero, and zero when the current is a maximum, *giving a phase difference of 90° between reverse pressure of self-induction and current.*

amperes, according to the scale; during some intermediate 10 degrees of the quarter revolution, as from B to C, the current increases from B′ to C′ or 2½ amperes, and during another 10 degrees as from D to E, at the end of one-quarter revolution where the sine curve reaches its amplitude, it rises and falls ½ ampere. It is thus seen that the *rate of change* varies from a maximum when the current is least, to zero when the current is at its maximum. Accordingly, the reverse pressure of self-induction *being proportional to the rate of change in the current strength,* is greatest when the current is at zero value, and zero when the current is at its maximum.

This relation is shown by curves in fig. 1,308, and it should be noted that *the reverse pressure and current are 90° apart* in phase. For this reason many alternating current problems may be solved graphically by the use of right angle triangles, the sides, drawn to some arbitrary scale, to represent the quantities involved, such as resistance, reactance, impedance, etc.

Properties of Right Angle Triangles.—In order to understand the graphical method of solving alternating current problems, it is necessary to know why certain relations exist between the sides of a right angle triangle. For instance, in every right angle triangle:

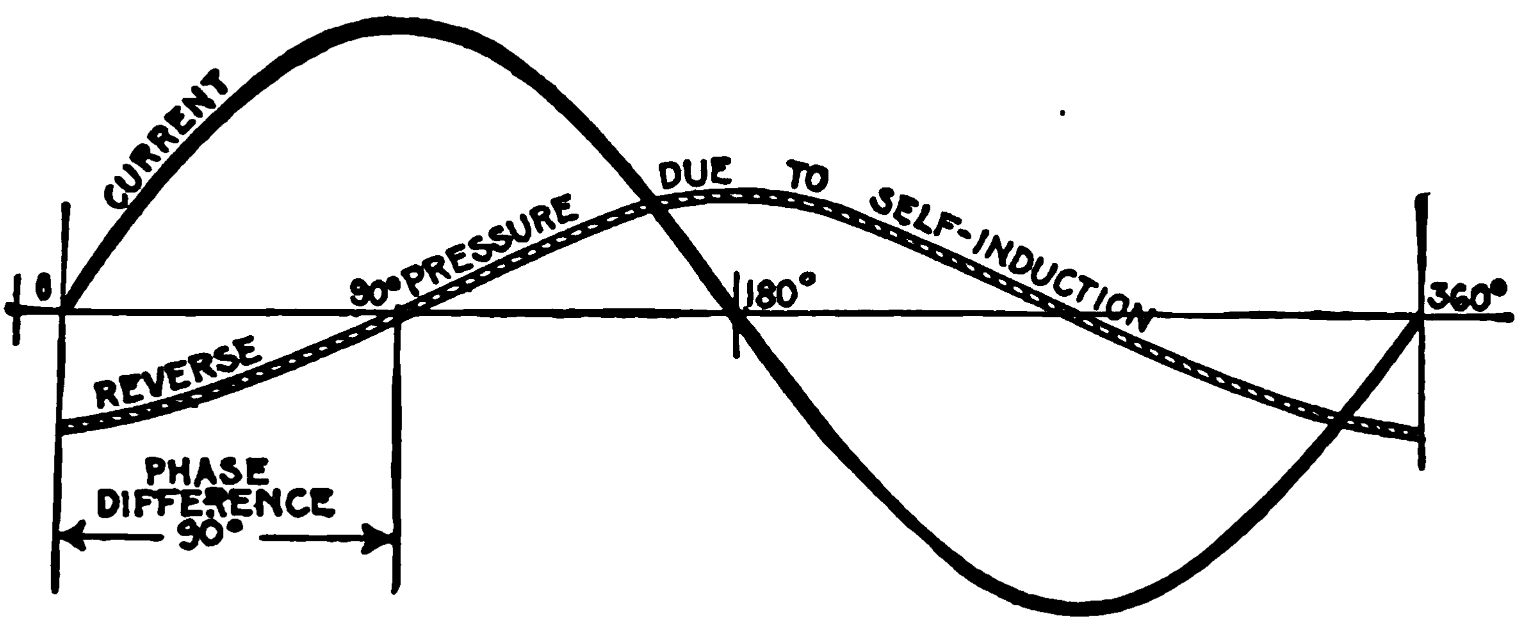


FIG. 1,308.—Sine curves showing phase relation between current and reverse pressure of self-induction. This reverse pressure, *being proportional to the rate of change in the current strength, is greatest when the current is at zero value, and zero when the current is maximum,* and in phase is 90° behind the current.

The square of the hypothenuse is equal to the sum of the squares on the other two sides.

That is, condensing this statement into the form of an equation:

$$hypothenuse^2 = base^2 + altitude^2 \ldots\ldots\ldots\ldots (1)$$

the horizontal side being called the base and the vertical side, the altitude.

This may be called the equation of the right angle triangle.

Ques. Why is the square of the hypothenuse of a right angle triangle equal to the sum of the squares of the other two sides?

Ans. This may be explained with the aid of fig. 1,309. Draw a line AB, 4 inches in length and erect a perpendicular BC, 3

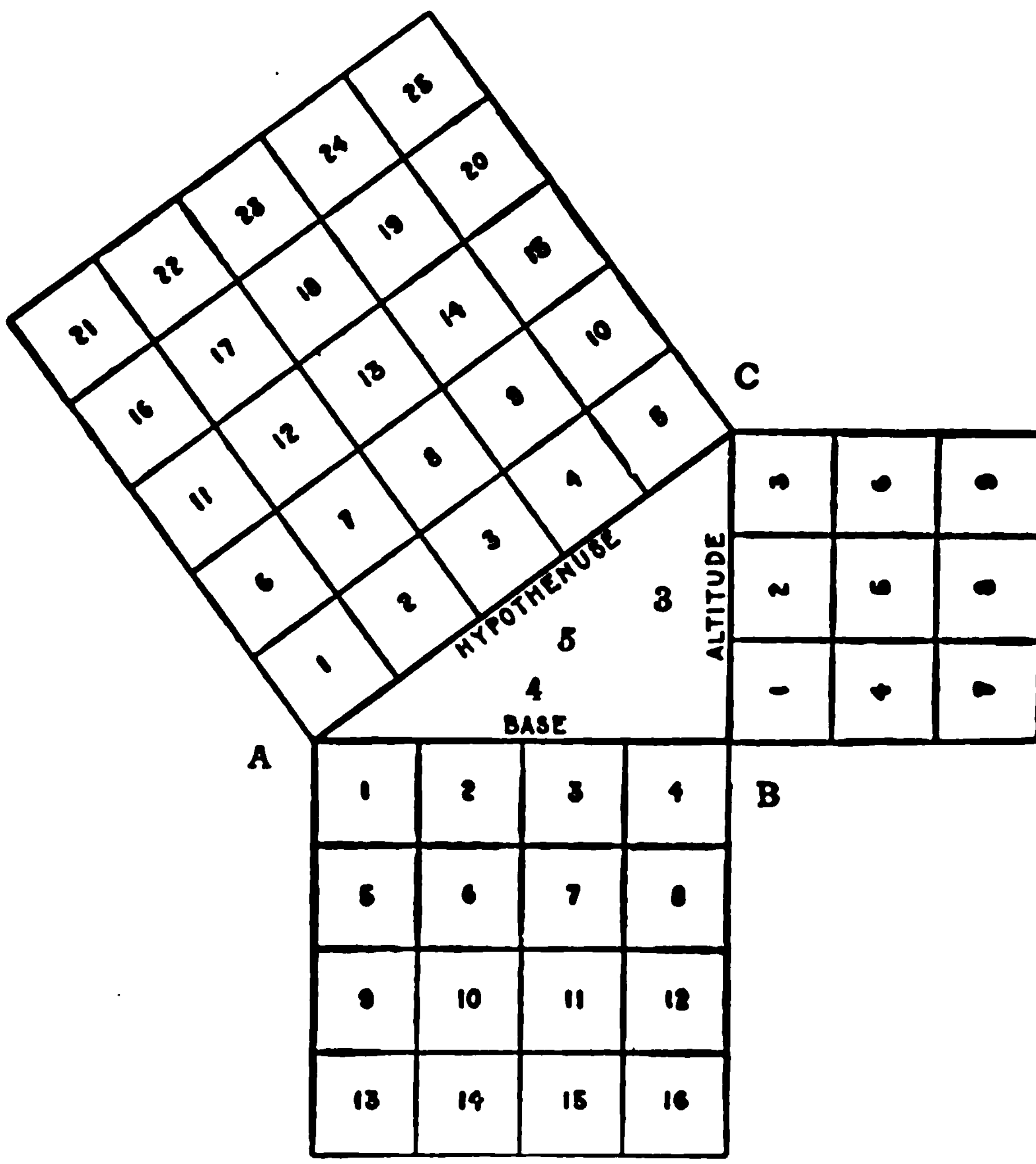


FIG. 1,309.—*In a right angle triangle the square on the hypothenuse is equal to the sum of the squares on the other two sides.* That is: *hypothenuse*^{2} = *base*^{2} + *altitude*^{2}. Draw AB, 4 inches long, and BC, 3 inches long and at right angles to A B. Join AC, which will be found to be 5 inches long. From the diagram, it must be clear that the square on AC = sum of squares on AB and BC; that is, $5^2 = 4^2 + 3^2$. Further, $4^2 = 5^2 - 3^2$; $3^2 = 5^2 - 4^2$; $5 = \sqrt{4^2 + 3^2}$; $4 = \sqrt{5^2 - 3^2}$; $3 = \sqrt{5^2 - 4^2}$.

inches in height; connect A and C, giving the right angle *triangle ABC. It* will be found that AC the hypothenuse of *this triangle is 5 inches* long. If squares be constructed on all

three sides of the triangle, the square on the hypothenuse will have an area of 25 sq. ins.; the square on the base, 16 sq. ins., and the square on the altitude, 9 sq. ins. Then from the figure $5^2=4^2+3^2$, that is $25=16+9$.

Repeating equation (1), it is evident from the figure that

$$\left.\begin{matrix} hypothenuse^2 \\ 5^2 \end{matrix}\right\} = \left\{\begin{matrix} base^2 & + & altitude^2 \\ 4^2 & + & 3^2 \end{matrix}\right\}$$

that is,

$$25 = 16 + 9.$$

In the right angle triangle, the following relations also hold:

$$base^2 = hypothenuse^2 - altitude^2 \ldots\ldots\ldots\ldots (2)$$

$$(4^2 = 5^2 - 3^2)$$

$$altitude^2 = hypothenuse^2 - base^2 \ldots\ldots\ldots\ldots (3)$$

$$(3^2 = 5^2 - 4^2)$$

In working impedance problems, it is not the square of any of the quantities which the sides of the triangle are used to represent that is required, but the quantities themselves, that is, the sides. Hence extracting the square root in equations (1), (2) and (3), the following are obtained:

$$hypothenuse = \sqrt{base^2 + altitude^2} \ldots\ldots\ldots\ldots (4)$$

$$(5 = \sqrt{4^2 + 3^2})$$

$$base = \sqrt{hypothenuse^2 - altitude^2} \ldots\ldots\ldots\ldots (5)$$

$$(4 = \sqrt{5^2 - 3^2})$$

$$altitude = \sqrt{hypothenuse^2 - base^2} \ldots\ldots\ldots\ldots (6)$$

$$(3 = \sqrt{5^2 - 4^2})$$

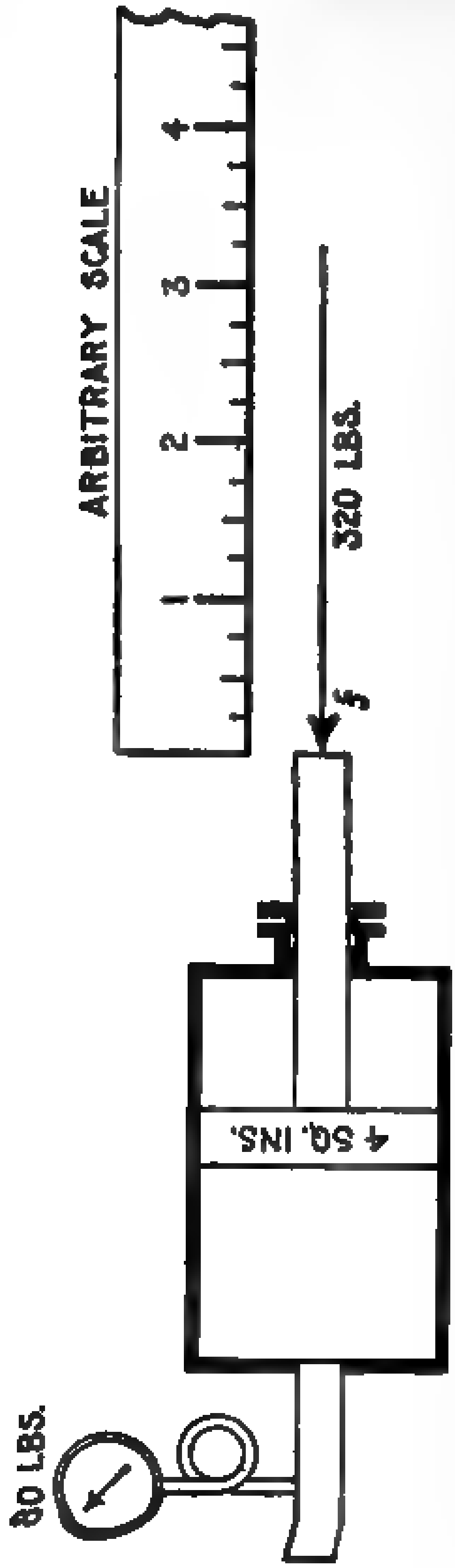


FIG. 1,310.—Diagram illustrating the representation of forces by straight lines. If 80 lbs. of steam be applied to a piston of 4 square inches area, the total pressure acting on the piston is $4 \times 80 = 320$ lbs. This may be balanced by an equal and opposite force. To represent the latter by a line, select any convenient scale whose divisions represent any convenient number of pounds—1, 3, 5, or, as here taken, 25 lbs. If the scale selected be divided into inches with ¼-inch divisions, then each ¼ inch represents a force of 25 lbs.; or, as usually stated, 1″ = 100 lbs. Strictly speaking 1″ is equivalent to 100 lbs. Draw the line $f = 3.2$ ins., then its length represents the magnitude of the force or 320 lbs., that is, $3.2 \times 100 = 320$ lbs.

Representation of Forces by Lines.—A single force may be represented in a drawing by a straight line, 1, the point of application of the force being indicated by an extremity of the line, 2, the intensity of the force by the length of the line, and 3, the direction of the force by the direction of the line, an arrow head being placed at an extremity defining the direction.

Thus in fig. 1,310, the force necessary to balance the thrust on the steam piston may be represented by the straight line *f* whose length measured on any convenient scale represents the intensity of the force, and whose direction represents the direction of the force.

Composition of Forces.—This is the operation of finding *a single force whose effect is the same as the combined effect of two or more given forces.* The required force is called the *resultant* of the given forces.

The composition of forces may be illustrated by the effect of the wind and tide on a sailboat as in fig. 1,311. Supposing the boat be acted upon by the wind so that in a given time, say half an hour, it would be moved in the direction and a distance represented by the line AB, and that in the same time the tide would carry it from A to C. Now, lay down AB, to any convenient scale, representing the effect of the wind, and AC that

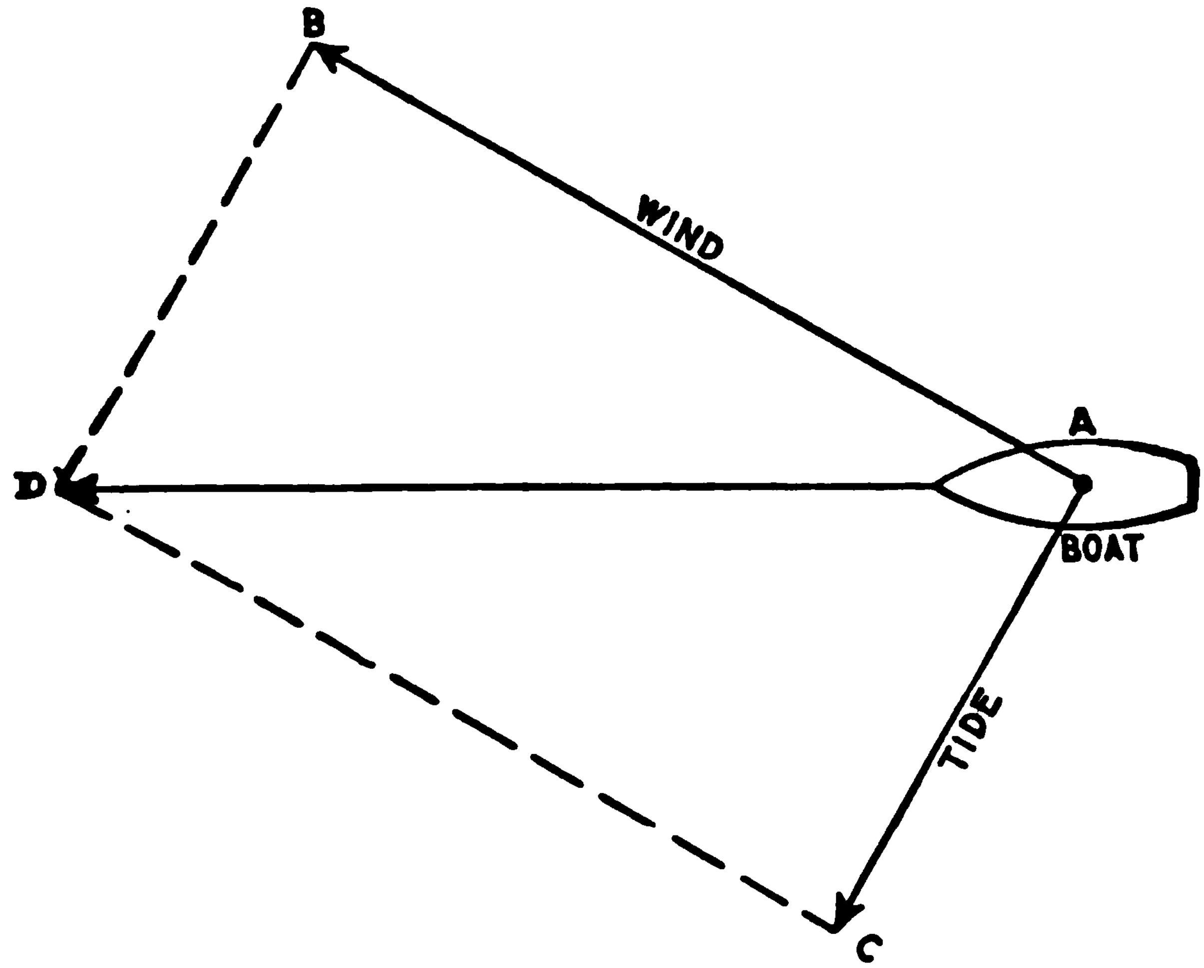


FIG. 1,311.—Parallelogram of forces for boat acted upon by both wind and tide.

of the tide, and draw BD equal and parallel to AC, and CD equal and parallel to AB, then the diagonal AD will represent the direction and distance the boat will move under the combined effect of wind and tide.

Ques. In fig. 1,311 what is the line AD called?

Ans. The *resultant*, that is, it represents the actual movement of the boat *resulting from the* combined forces of wind and tide.

Ques. What are the forces, AB and AC in fig. 1,31 represented by the sides of the parallelogram, and whic act upon a body to produce the resultant, called?

Ans. The *components.*

EXAMPLE.—Two forces, one of 3 lbs. and one of 4 lbs. act at point *a* in a body and at right angles, what is the resultant?

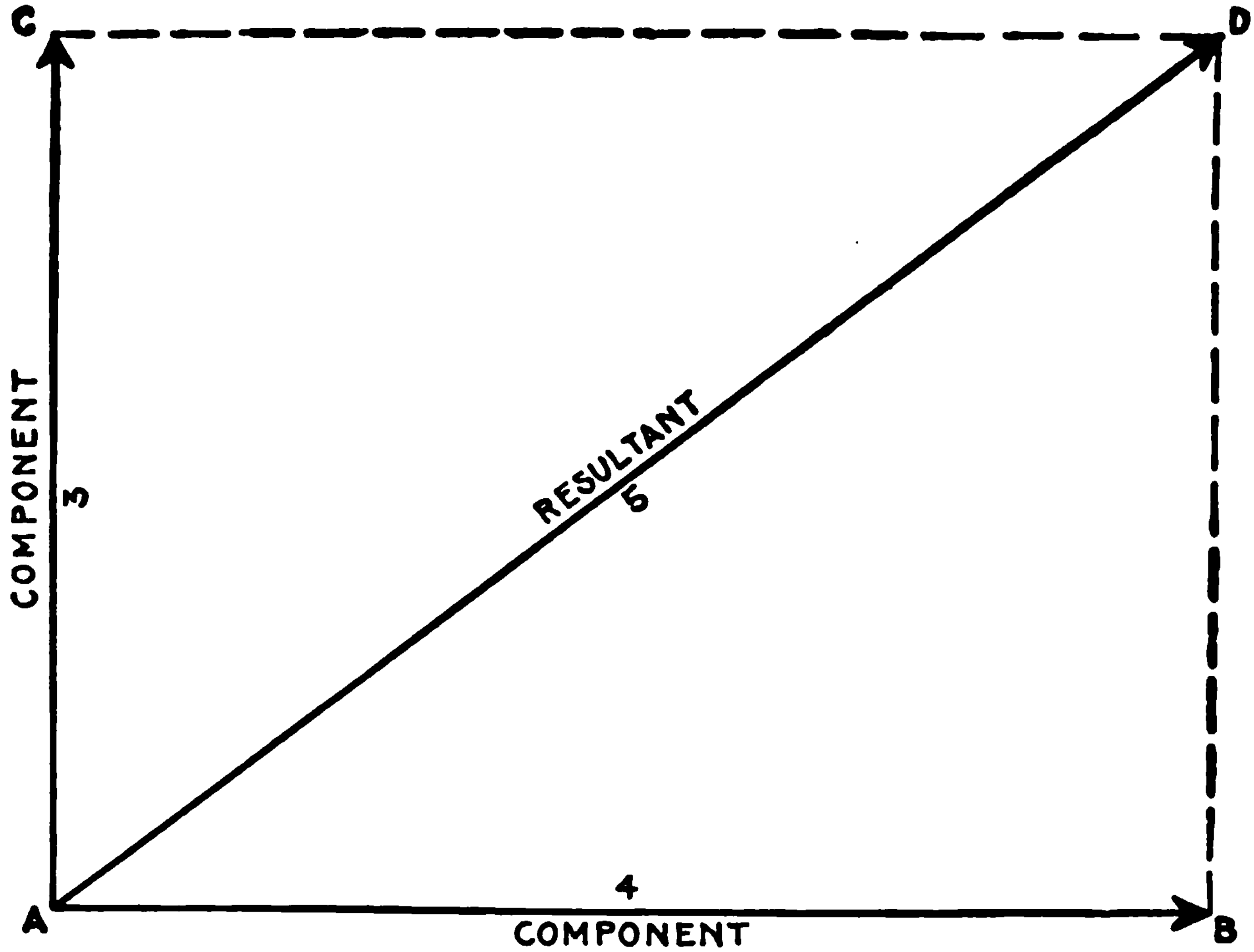


FIG. 1,312.—Parallelogram of forces; method of obtaining the resultant of two compone acting at right angles.

Take any convenient scale, say 1 in. = 1 lb., and lay off (fig. 131: AB = 4 ins. = 4 lbs.; also, AC (at right angles to AB) = 3 ins. = 3 ll Draw CD and BD parallel to AB and AC respectively, and join A The line AD is the resultant of the components AB and AC, and wh measured on the same scale from which AB and AC were drawn will found to be 5 inches long, which represents 5 lbs. acting in the directi AD.

Circuits containing Resistance and Inductance.— *circuits of this kind* where the impressed pressure encount

[redacted]

both resistance and inductance, it may be looked upon as split up into two components, as already explained, one of which is necessary to overcome the resistance, and the other, the inductance. That is, the impressed pressure is split up into

1. *Active pressure*, to overcome resistance;
2. *Self-induction pressure* to overcome inductance.

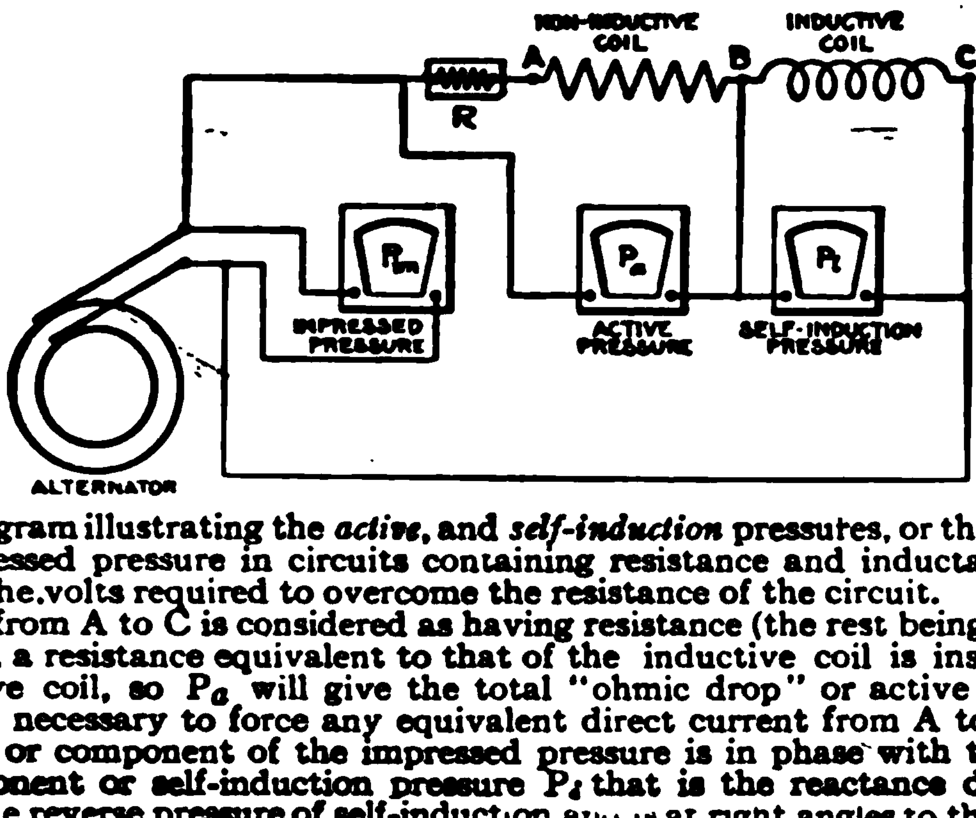


FIG. 1,313.—Diagram illustrating the *active*, and *self-induction* pressures, or the two components of the impressed pressure in circuits containing resistance and inductance. The active pressure is the volts required to overcome the resistance of the circuit. In the figure only the portion from A to C is considered as having resistance (the rest being negligibly small) except at R, a resistance equivalent to that of the inductive coil is inserted next to the non-inductive coil, so P_a will give the total "ohmic drop" or active pressure, that is, the pressure necessary to force any equivalent direct current from A to C. This active pressure P_a or component of the impressed pressure is in phase with the current. The other component or self-induction pressure P_i that is the reactance drop necessary to overcome the reverse pressure of self-induction and is at right angles to the current and 90° ahead of the current in phase. It is registered by a voltmeter between B and C, less the pressure due to ohmic resistance of the inductive coil. The impressed pressure P_{im} then or total pressure required to force electricity around the circuit *not including the resistance* R, (which is removed from the circuit when the reading of the impressed pressure is taken), is equal to the square root of the sum of the squares of the two components, that is, $P_{im} = \sqrt{P_a^2 + P_i^2}$

The active pressure is *in phase with the current.*

The self induction pressure is *at right angles to the current and 90 degrees ahead of the current in phase.*

Ques. Why is the active pressure in phase with the current?

Ans. The pressure used in overcoming resistance is from Ohm's law, E = RI. Hence, when the current is zero, E is zero, and when the current is a maximum E is a maximum. Hence, that component of the impressed pressure necessary to overcome the *resistance must be in phase with the current.*

Ques. Why is this?

Ans. Since the *reverse pressure of self induction* is 90° behind the current, the component of the impressed pressure necessary to overcome the reverse pressure of self induction, being opposite to this, will be represented as being 90° ahead of the current.

The distinction between the reverse pressure of self-induction, that is, the induced pressure, and the pressure necessary to overcome self-induction should be carefully noted. They are two equal and opposite

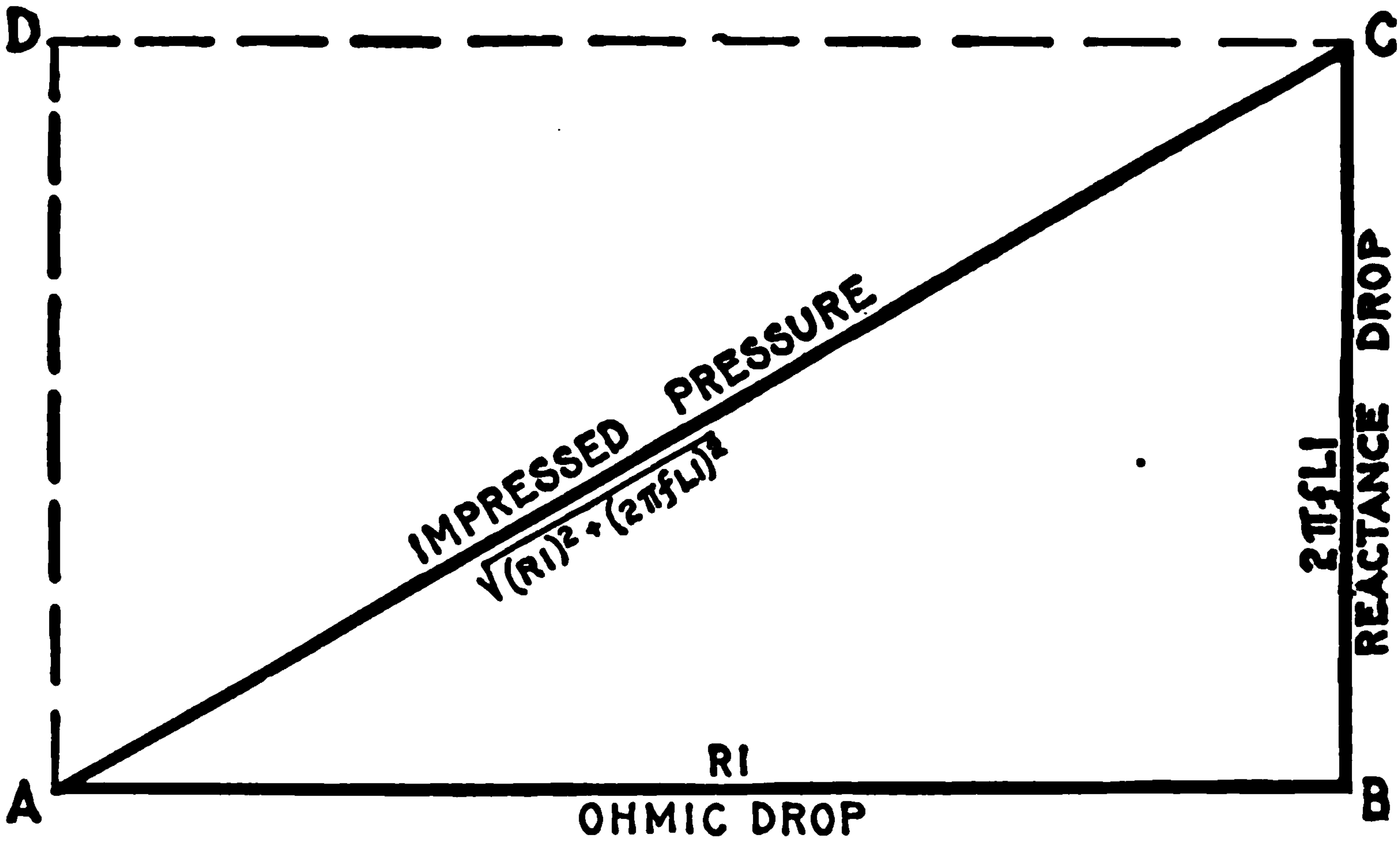


FIG. 1,314.—Graphical method of obtaining the impressed pressure in circuits containing resistance and inductance, having given the ohmic drop and reactance drop due to inductance. With any convenient scale lay off AB = ohmic drop and erect the perpendicular BC = reactance drop (using same scale). Join AC, whose length (measured with same scale) will give the impressed pressure. Constructing a parallelogram with dotted lines AD and CD, it is evident that AC is the *resultant* of the two *components* AB and BC, or its equal AD.

forces, that is, two balancing forces just as is shown in fig. 1,310. Here, in analogy, the thrust of the piston may represent the induced pressure and the equal and opposite force indicated by the arrow *f*, the component of the impressed pressure necessary to balance the induced pressure.

The Active Pressure or "Ohmic Drop."—The component of the *impressed pressure* necessary to overcome resistance, is from Ohm's law:

active pressure = ohmic resistance × virtual current

that is

$$E_a = R_o I_v \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

this is the "ohmic drop" and may be represented by a line AB, fig. 1,314 drawn to any convenient scale, as for instance, 1 in. = 10 volts.

The Self-induction Pressure or "Reactance Drop."—The component of the impressed pressure necessary to overcome the induced pressure, is from Ohm's law:

inductance pressure = inductance reactance × virtual current;

that is,

$$E_i = X_i I_v \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

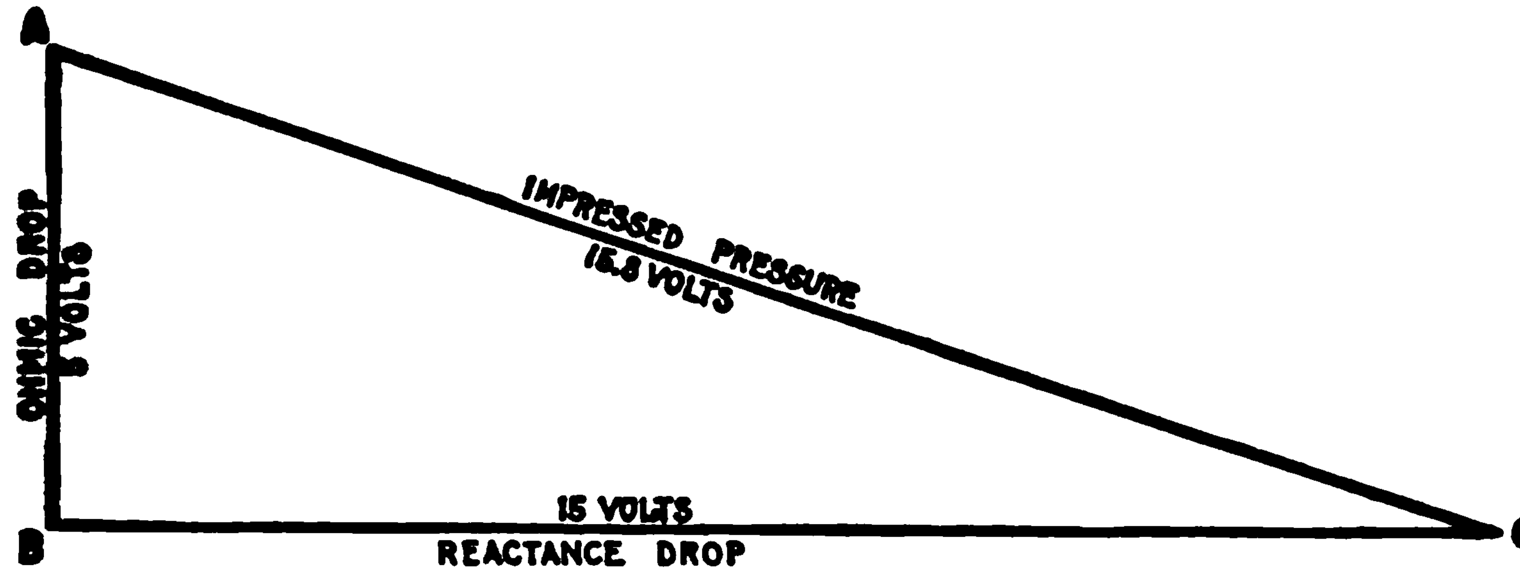


FIG. 1,315.—Diagram for impressed pressure on circuit containing 5 volts ohmic drop and 15 volts reactance drop.

Now the reactance X_i, that is the spurious resistance, is obtained from the formula

$$X_i = 2\pi fL \ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

as explained on page 1,038, and in order to obtain the volts necessary to overcome this spurious resistance, that is, the "reactance drop" as it is called, the value of X_i in equation (3) must be substituted in equation (2), giving

$$E_i = 2\pi fLI \ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

writing simply I for the virtual pressure.

Since the pressure impressed on a circuit is considered as made up of two components, one in phase with the current and one at right angles to the current, the component E_i or "reactance drop" as given in equation (4) may be represented by the line BC in fig. 1,314, at right angles to AB, and of a length BC, measured with the same scale as was measured AB, *to correspond to the* value indicated by equation (4).

EXAMPLE.—In an alternating circuit, having an ohmic drop of 5 volts, and a reactance drop of 15 volts, what is the impressed pressure?

With a scale of say, $\frac{1}{4}$ inch = one volt, lay off, in fig. 1,315, AB = 5 volts = $1\frac{1}{4}$ in., and, at right angles to it, BC = 15 volts = $\frac{15}{4}$ or $3\frac{3}{4}$ ins. Join AC; this measures 3.95 inches, which is equivalent to $3.95 \times 4 = 15.8$ volts, the impressed pressure. By using good paper, such as bristol board, a

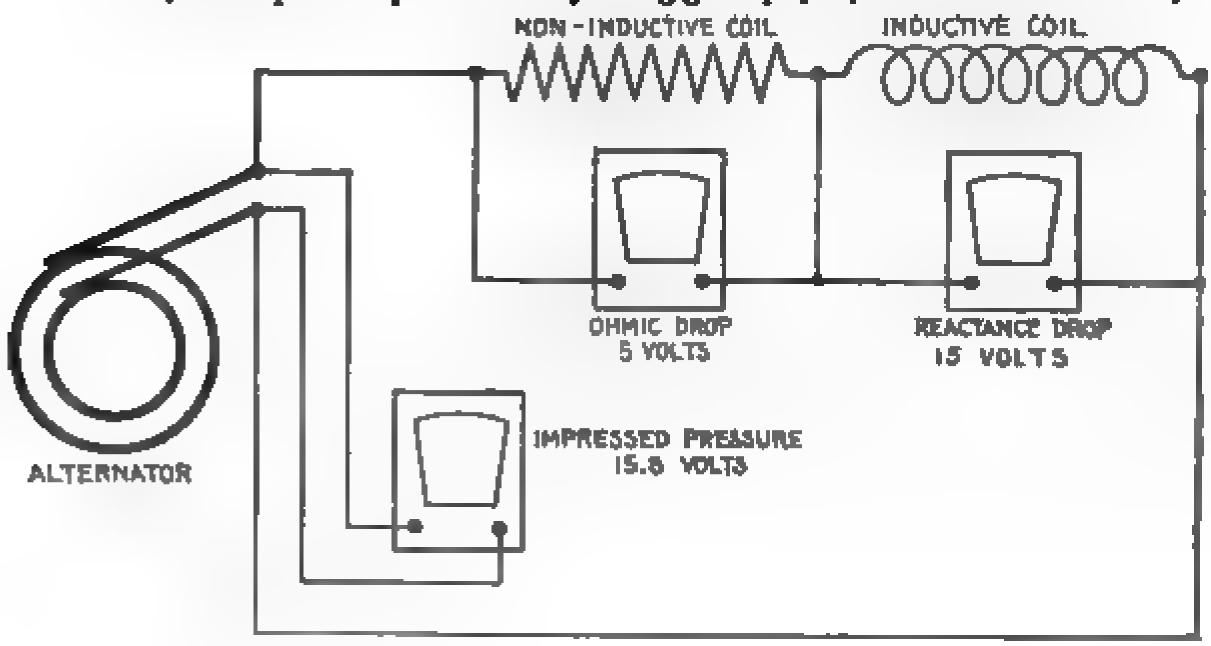


FIG. 1,316.—Diagram of circuit containing 5 volts ohmic drop, and 15 volts reactance drop.

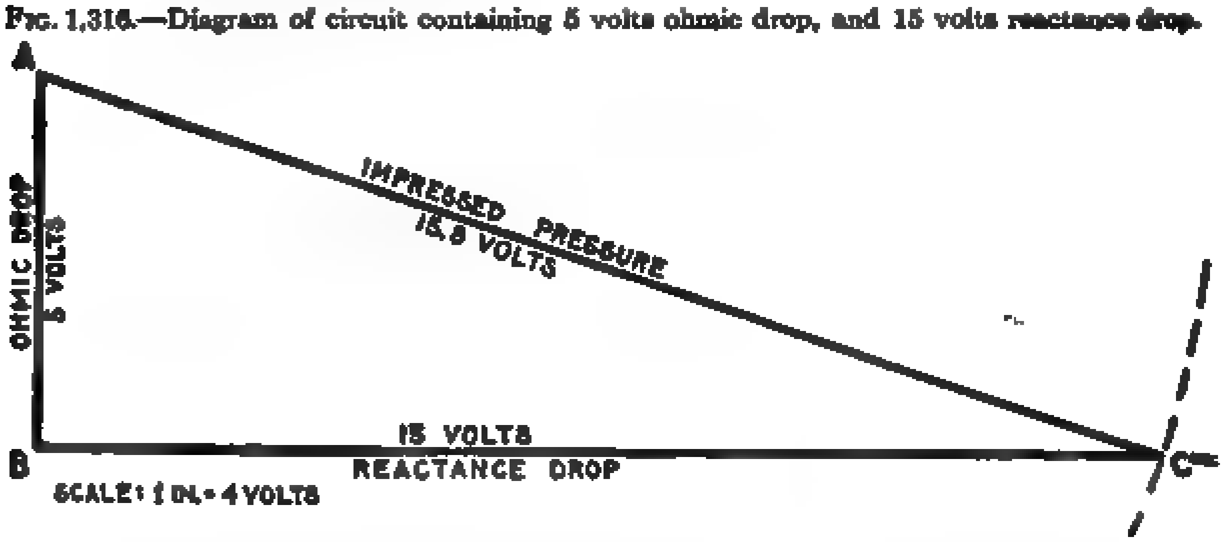
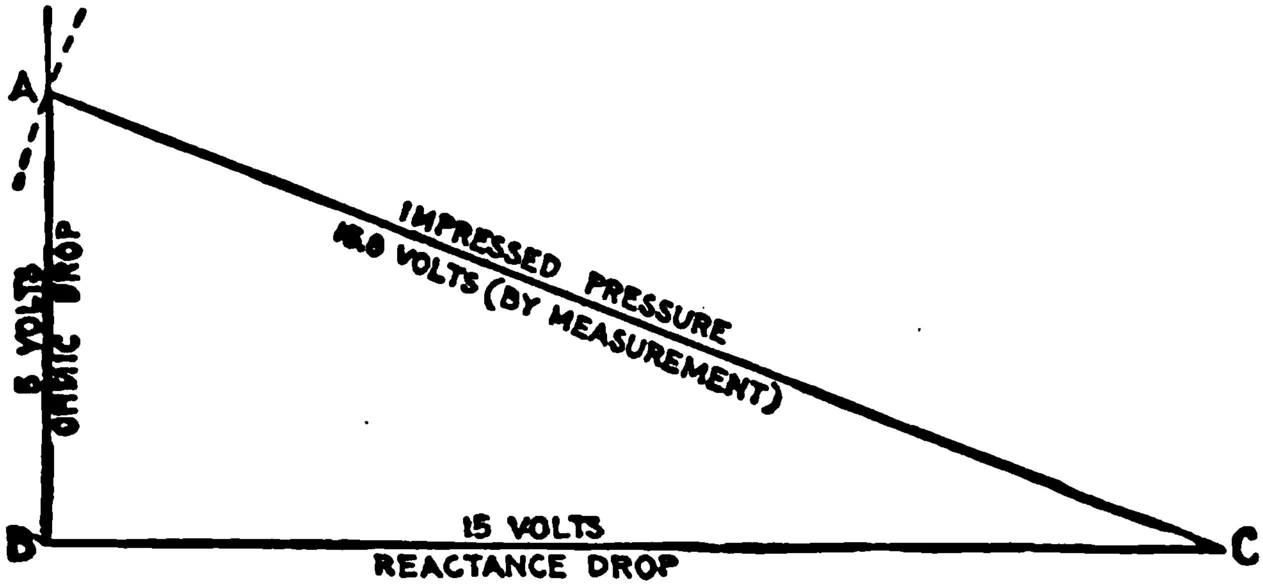


FIG. 1,317.—Diagram for obtaining reactance drop in circuit containing 5 volts ohmic drop, and 15.8 volts impressed pressure.

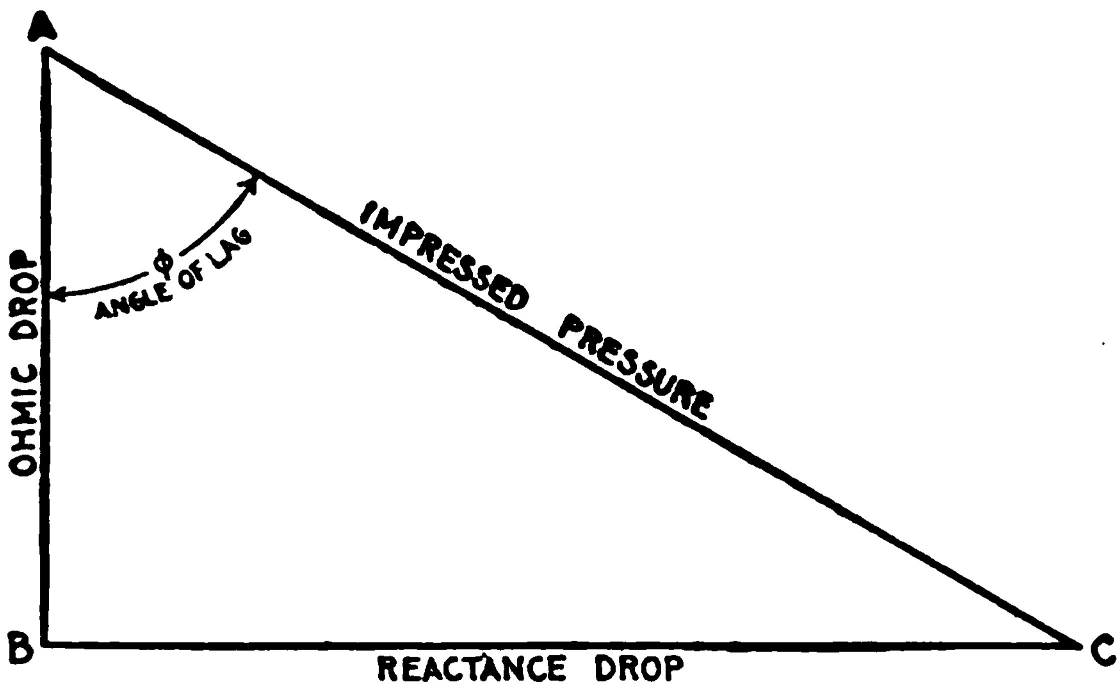
6H pencil, engineers' scale and triangles or square, such problems are solved with precision. By calculation impressed pressure = $\sqrt{5^2+15^2}$ = 15.8 volts. Note that the diagram is drawn with the side BC horizontal *instead of AB—simply to save space.*

EXAMPLE.—In an alternating circuit, having an ohmic drop of 5 volts and an impressed pressure of 15.8 volts, what is the reactance drop?

In fig. 1,317, draw a horizontal line of indefinite length and at any point B erect a perpendicular AB = 5 volts. With A as center and radius of length equivalent to 15.8 volts, describe an arc cutting the horizontal line at C. This gives BC, the reactance drop required, which by measurement is 15 volts.



1,318.—Diagram for obtaining ohmic drop in the circuit fig. 1,316 when impressed pressure and reactance drop are given. Lay off BC to scale = reactance drop; draw AB at right angle and of indefinite length; with C as center and radius of length = impressed pressure, describe an arc cutting ohmic drop line at A, then AB = ohmic drop = 5 volts by measurement.



1,319.—Graphical method of finding angle of lag when the ohmic drop and reactance drop are given. The angle of lag ϕ, is that angle included between the impressed pressure and the ohmic drop lines, that is, between AC and AB.

EXAMPLE.—An alternating current of 10 amperes having a frequency of 60, is impressed on a circuit containing a resistance of 5 ohms and an inductance of 15 milli-henrys. What is the impressed pressure?

The *active pressure or ohmic* drop is $5 \times 10 = 50$ volts.

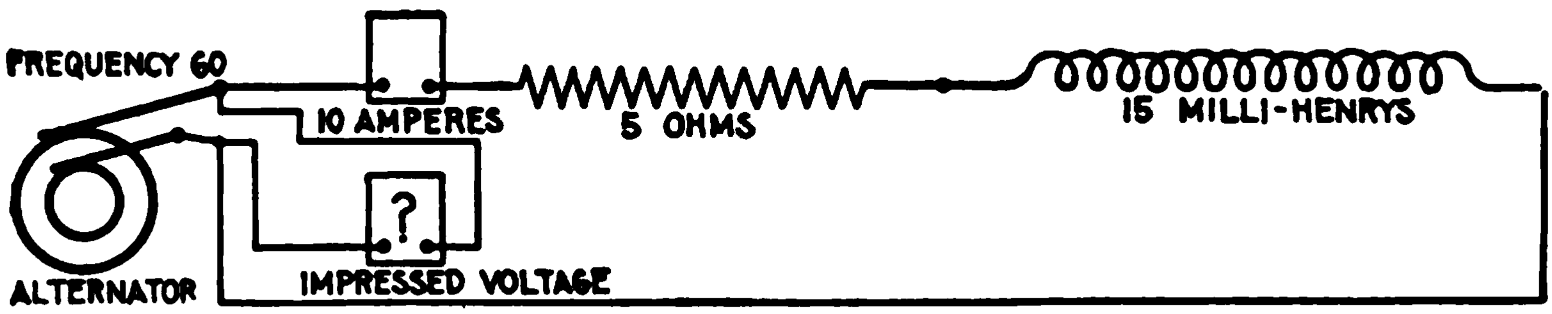


FIG. 1,320.—Diagram of circuit containing 5 ohms resistance, 15 milli-henrys inductance, with 8 ampere 60 frequency current.

The inductance reactance or X_i = is $2 \times 3.1416 \times 60 \times .015 = 5.66$ ohms Substituting this and the current value 10 amperes in the formula for inductance pressure or reactance drop (equation 2 on page 1,077) gives $E_i = 5.65 \times 10 = 56.5$ volts.

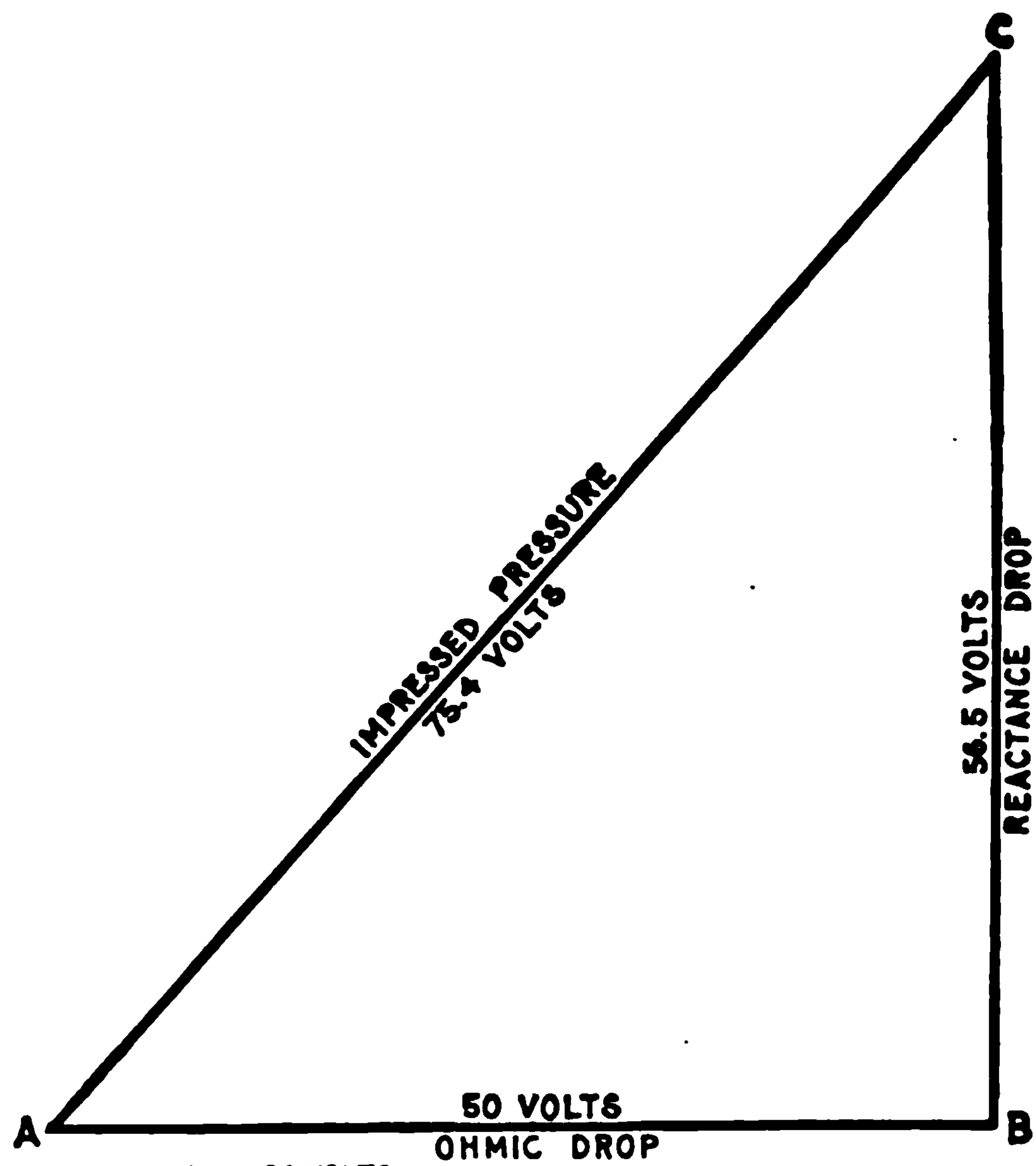


FIG. 1,321.—Diagram for impressed pressure on circuit containing 5 ohms resistance and *inductance of 15 milli-henrys*, the current being 10 amperes with frequency of 60.

In fig. 1,321, lay of AB = 50 volts, and BC = 56.6 volts. Using a scale *of 20 volts to the inch gives* AB = 2.5 ins., and BC = 2.83 ins. Joining *AC gives the impressed voltage*, which by measurement is 75.4 volts.

In some problems it is required to find the impedance of a circuit in which the ohmic and spurious resistances are given. This is done in a manner similar to finding the impressed pressure.

Ohmic resistance and spurious resistance or inductance reactance both tend to reduce an alternating current. Their

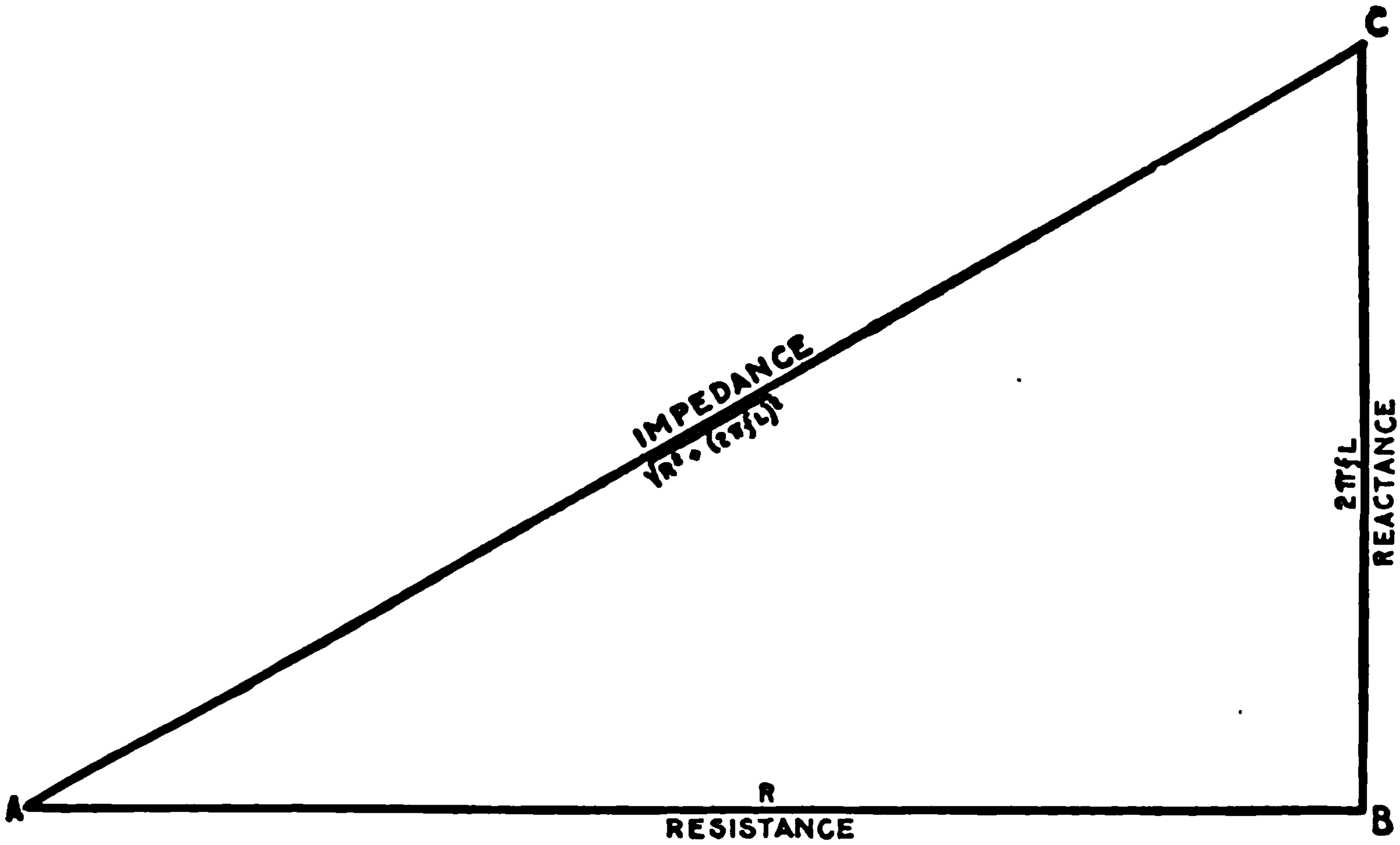


FIG. 1,322.—Graphical method of obtaining the impedance in circuits containing resistance and inductance, having given the resistance and reactance, that is, the ohmic resistance and spurious resistance. With any convenient scale lay off AB = *resistance*, and erect the perpendicular BC = *reactance* (using the same scale); join AC, whose length (measured with the same scale) will give the *impedance*.

combined action or impedance is equal to the square root of the sum of their squares, that is,

$$\textit{impedance} = \sqrt{\textit{resistance}^2 + \textit{reactance}^2}$$

This relation is represented graphically by the side of a right angle triangle as in fig. 1322, in which the hypothenuse corresponds to the *impedance, and the sides* to the resistance and reactance.

EXAMPLE.—In a certain circuit the resistance is 4 ohms, and th *reactance 3 ohms.* What is the impedance?

In fig. 1,323, lay off, on any scale AB = 4 ohms and erect the perpendicular BC = 3 ohms. Join AC, which gives the impedance, and which is, measured with the same scale, 5 ohms.

EXAMPLE.—A coil of wire has a resistance of 20 ohms and an inductance of 15 milli-henrys. What is its impedance for a current having a frequency of 100?

FIG. 1,323.—Diagram for obtaining the impedance of a circuit containing 4 ohms resistance and 3 ohms reactance.

The ohmic value of the inductance, that is, the reactance is

$$2\pi f L = 2 \times 3.1416 \times 100 \times .015 = 9.42 \text{ ohms.}$$

In fig. 1,324, lay off, on any scale, AB = 20 ohms, and the perpendicular BC to length = 9.42 ohms. Join AC, which gives the impedance, which is, measured on the same scale, 22.1 ohms.

EXAMPLE.—What is the angle of lag in a circuit having a resistance of 4 ohms and a reactance of 3 ohms?

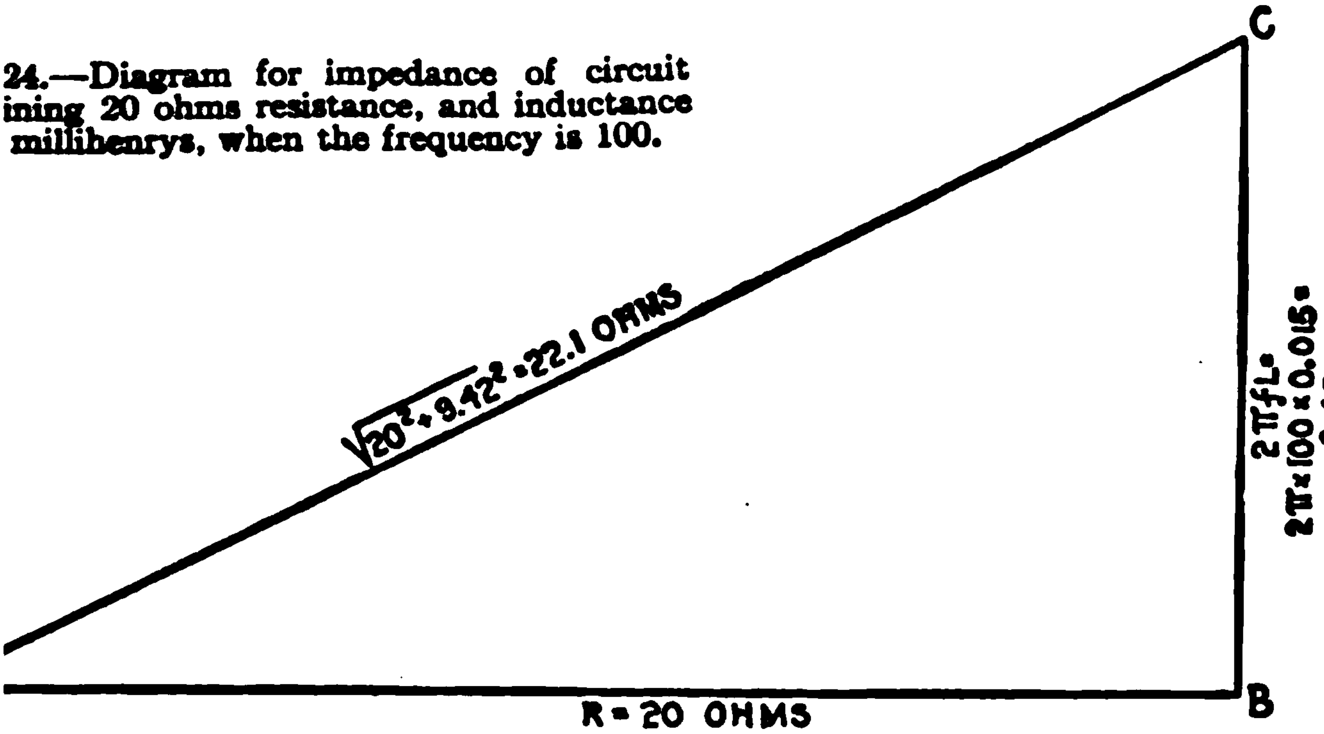
Construct the impedance diagram in the usual way as in fig. 1,325, *then the angle included* between the impedance and resistance lines

lenoted by ϕ) is the angle of lag, that is, the angle BAC. By measure-
ient with a protractor it is 37 degrees. By calculation the tangent of the
ngle of lag or

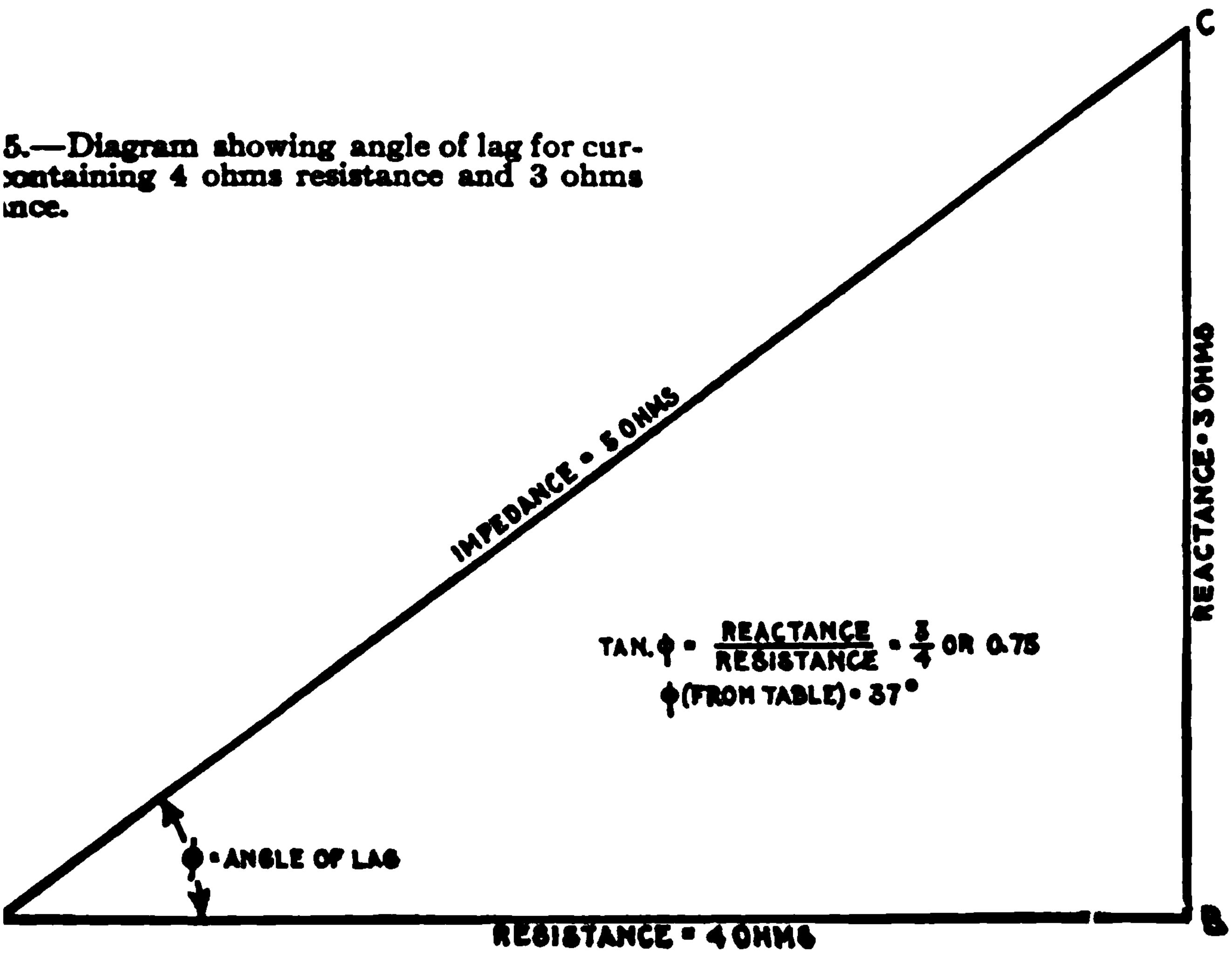
$$\tan\phi = \frac{BC}{AB} = \frac{3}{4} \text{ or } .75$$

From the table on page 451, the angle is approximately 37°.

24.—Diagram for impedance of circuit ining 20 ohms resistance, and inductance millihenrys, when the frequency is 100.



5.—Diagram showing angle of lag for cur- ontaining 4 ohms resistance and 3 ohms nce.



Circuits containing Resistance and Capacity.—The effect of capacity in an alternating current circuit is to cause the current to lead the pressure, since the reaction of a condenser, instead of tending to prolong the current, tends to drive it back.

Careful distinction should be made between capacity *in series* with a circuit and capacity *in parallel* with a branch of a circuit. The discussion here refers to capacity in series, which

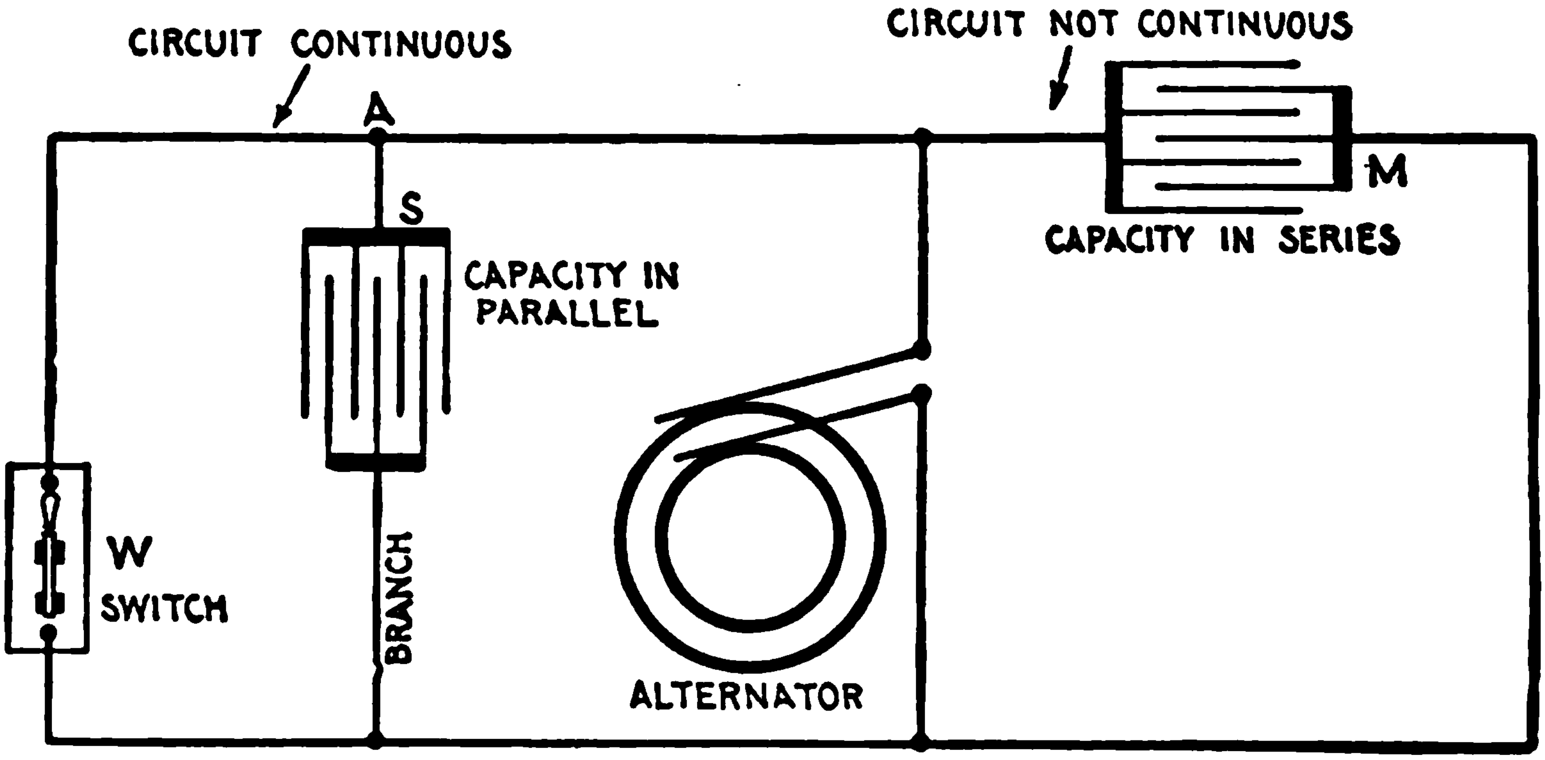


FIG. 1,326.—Circuit diagram illustrating the distinction between *capacity in series* and *capacity in parallel*. The condition for *capacity in series* is that the circuit must be discontinuous as at M; for *capacity in parallel* the main circuit must be continuous; this means that the capacity must be inserted in a branch of the main circuit as at A. In the figure the capacity S is connected *in series* with respect to the branch, that is, the branch is discontinuous, but it is *in parallel* with respect to the main circuit, when the latter is continuous, that is, when the switch W is closed. If W be opened, the main circuit becomes discontinuous and S is changed from *in parallel* to *in series* connection.

means that the circuit is not continuous but the ends are joined to a condenser, as shown at the right in fig. 1,326, so that no current can flow except into and out of the condenser.

Ques. In circuits containing resistance and capacity upon what does the amount of lead depend?

Ans. Upon the relative values of the resistance and the capacity reactance.

Ques. Describe the action of a condenser when current is applied.

Ans. When the current begins to flow into a condenser, that is, when the flow is maximum, the back pressure set up by the condenser (called the *condenser pressure*) is zero, and when the flow finally becomes zero, the condenser pressure is a maximum.

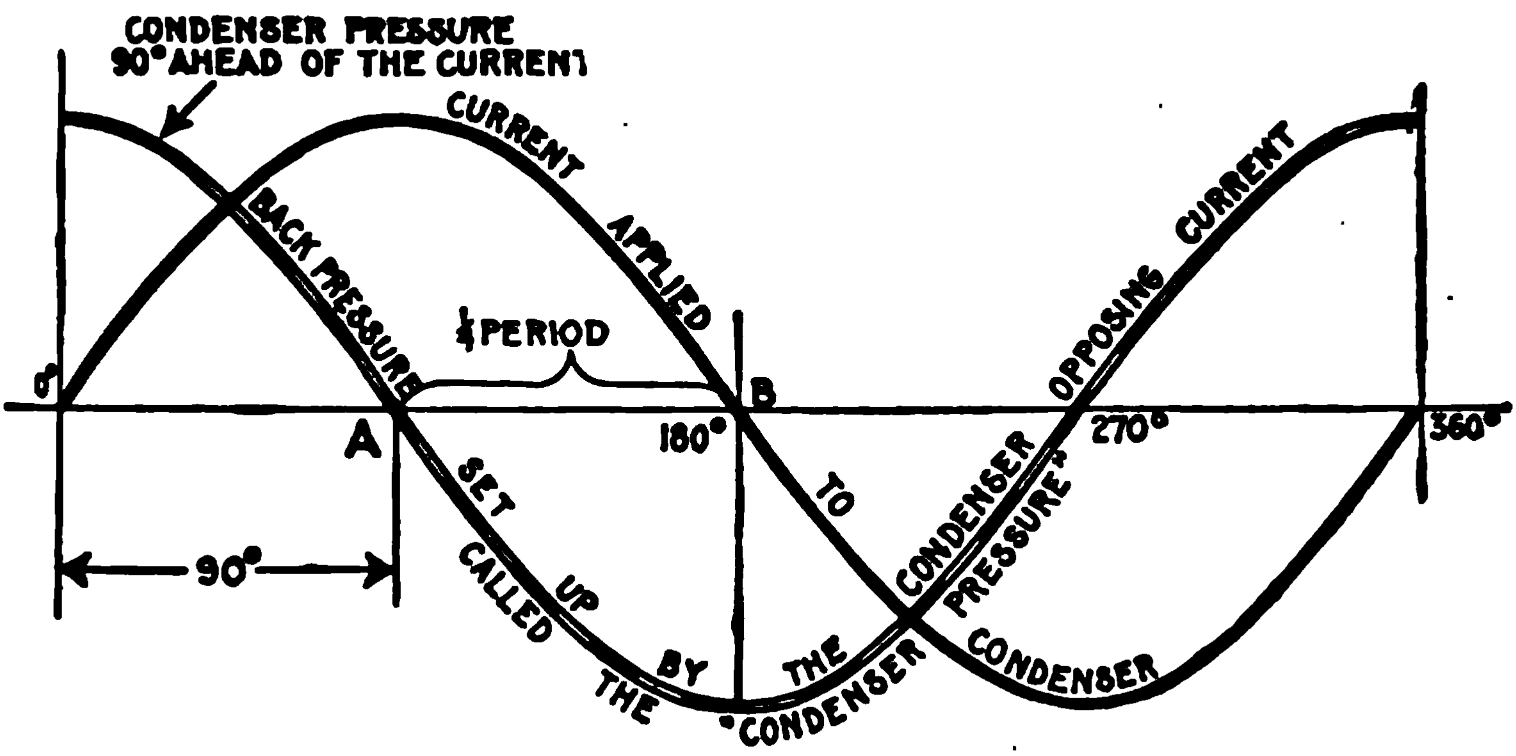


FIG. 1,327.—Current and pressure curves showing that the condenser pressure is 90° ahead of the current. A current flowing into a condenser encounters a gradually increasing pressure which opposes it, beginning from zero pressure when the current enters at maximum flow and increasing to the same value as the current pressure, at which time the current ceases to flow. Hence, since the current varies from zero to maximum in one quarter period, or 90°, the phase difference between current and condenser pressure is 90°. The condenser pressure reaching a positive maximum when the current starts from zero on the positive wave, is 90° ahead of the current.

Ques. What does this indicate?

Ans. It shows that the phase difference between the wave representing the condenser pressure and the current is 90°, as illustrated in fig. 1,327.

Ques. Is the condenser pressure ahead or behind the current and why?

Ans. It is ahead of the current. The condenser pressure, when the condenser is discharged being zero, the current enters

at maximum velocity as at *A* in fig. 1,327, and gradually decreases to zero as the condenser pressure rises to maximum at B, this change taking place in one-quarter period. Thus the condenser pressure, which opposes the current, being at a maximum when the current begins its cycle is 90° *ahead of the current*, as is more clearly seen in the last quarter of the cycle (fig. 1,327).

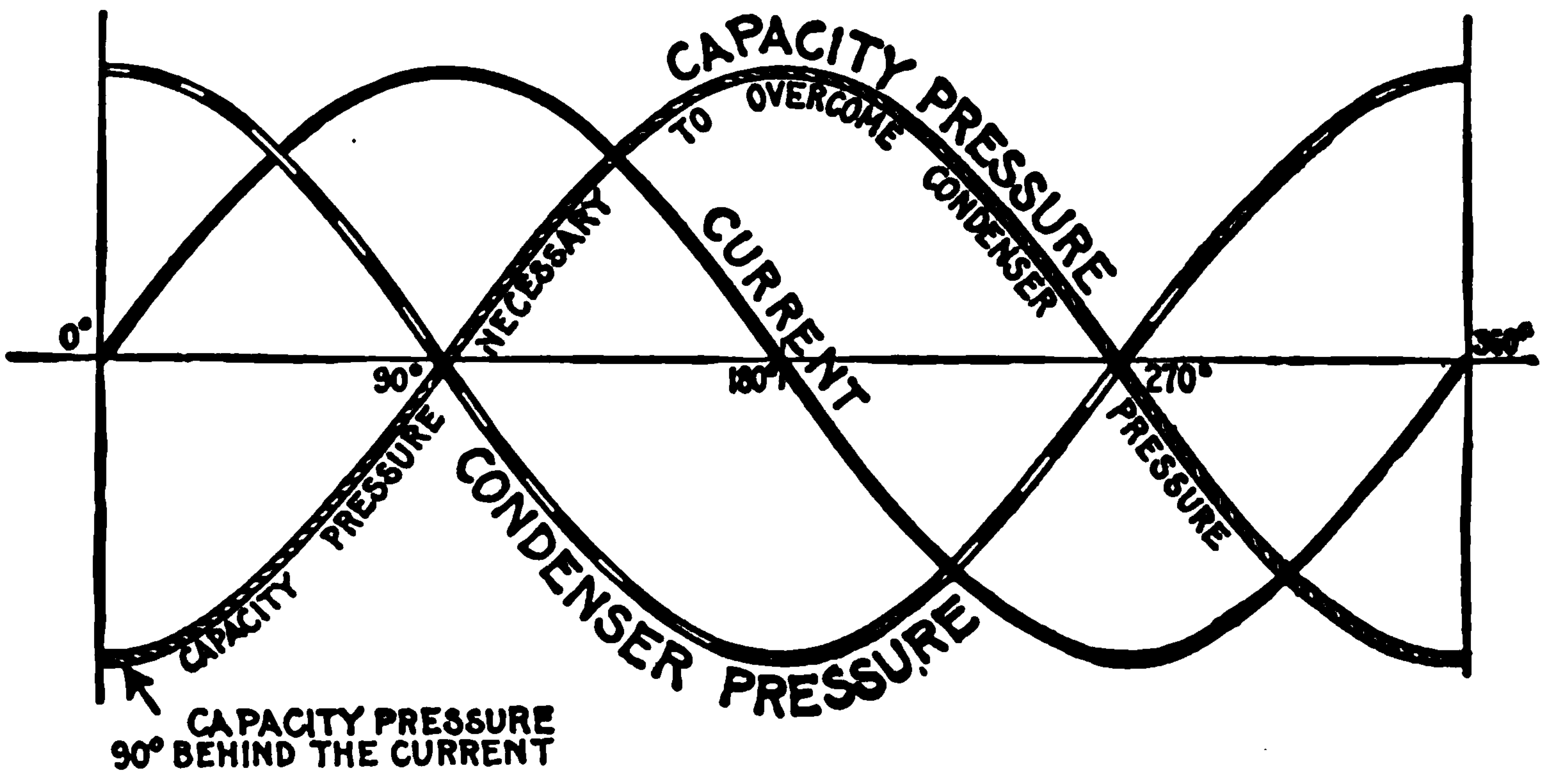


FIG. 1,328.—Current and pressure curves, showing phase relation between the current, condenser pressure, and impressed or *capacity* pressure necessary to overcome the condenser pressure. The capacity pressure, since it must overcome the condenser pressure, is equal and opposite to the condenser pressure, that is, the phase difference is 180°. The condenser pressure being 90° *ahead* of the current, the impressed pressure is 90° *behind* the current.

Ques. What is the phase relation between the condenser pressure and the pressure applied to the condenser to overcome the condenser pressure?

Ans. The pressure applied to the condenser to overcome the condenser pressure, or as it is called, the *capacity pressure*, must be opposite to the condenser pressure, or 90° *behind the current.*

In circuits containing resistance and capacity, the total pressure impressed on the circuit, or *impressed pressure*, as it is called, is made up of two components:

1. The *active pressure*, or pressure necessary to overcome the resistance;

   The active pressure is in phase with the current.

2. The *capacity pressure*, or pressure necessary to overcome the condenser pressure,

   The capacity pressure is 90 degrees behind the current.

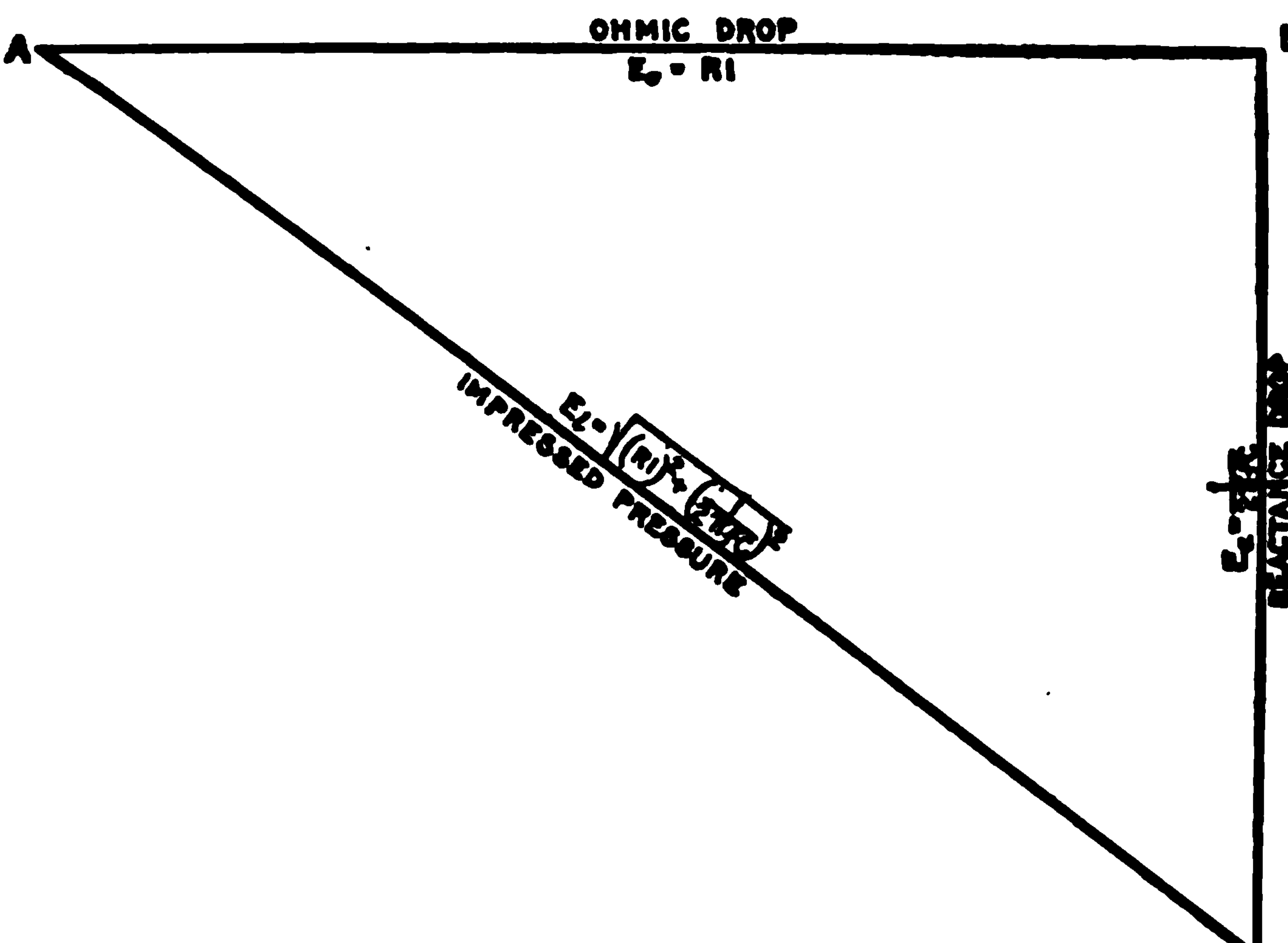


FIG. 1,329.—Graphical method of obtaining the impressed pressure in circuits containing resistance and capacity, having given the ohmic drop and reactance drop due to capacity. With any convenient scale, lay off AB = *ohmic drop*, and at right angles to AB draw BC = *reactance drop* (using the same scale). Join AC, whose length (measured with the same scale) will give the *impressed pressure*. The mathematical expressions for the three quantities are given inside the triangle, and explained in the text.

Problems involving resistance and capacity are solved similarly to those including resistance and inductance.

The Active Pressure or "Ohmic Drop."—This, as before explained *is represented, in fig. 1,329, by* a line AB, which in magnitude equals, *by Ohm's law, the product* of the resistance multiplied by the current, *that is,*

$$E_a = R_o I_g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The Capacity Pressure or "Reactance Drop."—This component of the impressed pressure, is, applying Ohm's law,

capacity pressure = capacity reactance × virtual current.

$$E_c = X_c\, I_v \quad \text{.......................... (2)}$$

That is, the expression for capacity reactance X_c, that is, for the value of capacity in ohms is, as explained on page 1,048,

$$X_c = \frac{1}{2\pi f C} \quad \text{....................... (3)}$$

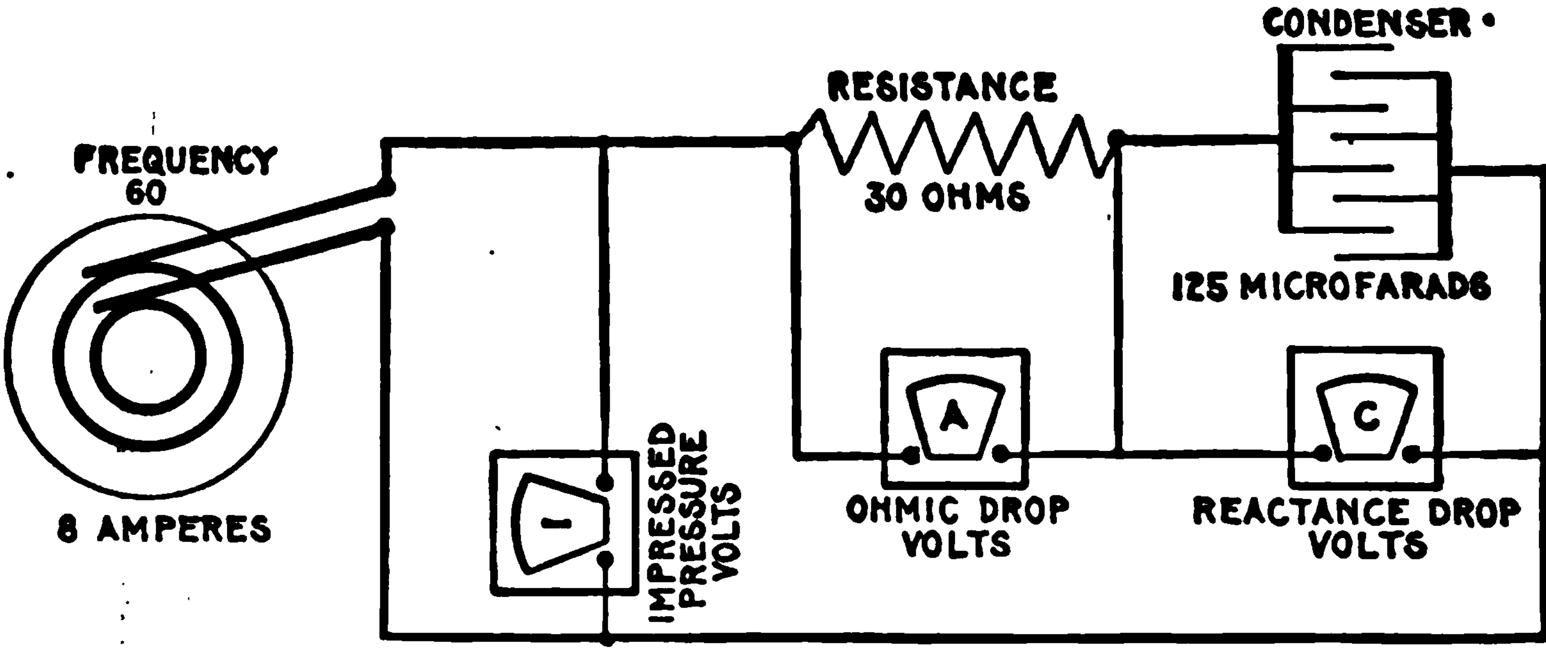


FIG. 1,330.—Diagram of circuit containing a resistance of 30 ohms and capacity of 125 microfarads. The calculation for impressed pressure, ohmic drop, and reactance drop for a current of 8 amperes at frequency 60 is given in the example on page 1,089, the diagram for impressed pressure being given in fig. 1,331.

Substituting this value of X_c in equation (2) and writing I for virtual current.

$$E_c = \frac{I}{2\pi f C} \quad \text{.................... (4)}$$

CAUTION —The reader should distinguish between the 1 (one) in (3) and the letter I in (4); both look alike.

Since the capacity pressure is 90° *behind* the current, it is represented in fig. 1,329, by a line BC, drawn *downward*, at right angles to AB, and of a length corresponding to the capacity pressure, that is, to the reactance drop.

The Impressed Pressure.—Having determined the ohmic and reactance drops and represented them in the diagram, fig. 1,329, by lines AB and BC respectively, a line AC joining A and C, will then be the resultant of the two component pressures, that is, it will represent the *impressed pressure* or total pressure applied to the circuit.

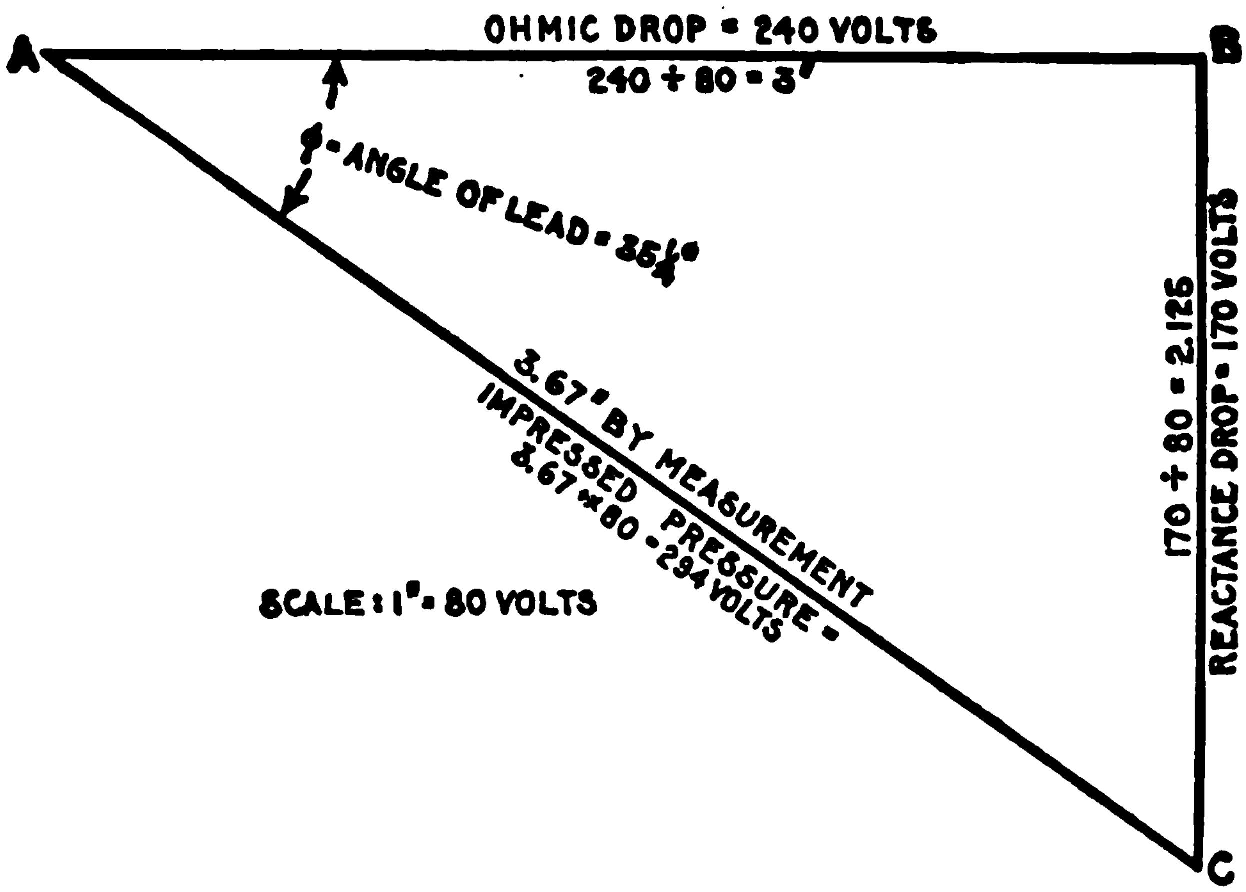
In the diagram it should be noted that the active pressure is called the *ohmic drop,* and the capacity pressure, the *reactance drop.*

EXAMPLE.—A circuit as shown in fig. 1,330 contains a resistance of 30 ohms, and a capacity of 125 microfarads. If an alternating current of 8 amperes with frequency 60 be flowing in the circuit, what is the ohmic drop, the reactance drop, and the impressed pressure?

The ohmic drop or active pressure is, substituting in formula (1) on page 1,087,

$$E_a = 30 \times 8 = 240 \text{ volts}$$

which is the reading of voltmeter A in fig. 1,330.



G. 1,331.—Diagram for obtaining the impressed pressure of the circuit shown in fig. 1,330.

The reactance drop or

$$E_c = \frac{I}{2\pi f C} = \frac{8}{2 \times 3.1416 \times 60 \times .000125} = 170 \text{ volts}$$

in substituting, note that the capacity C of 125 microfarads is reduced to .000125 farad.

Using a scale of say 1 inch = 80 volts, lay off in fig. 1,331, AB equal to the ohmic drop of 240 volts; on this scale AB = 3 inches. Lay off at right angles, BC = reactance drop = 170 volts = 2.125 inches. Join AC, which gives the impressed voltage, (that is the reading of voltmeter I in fig. 1,330,) which measures 294 volts.

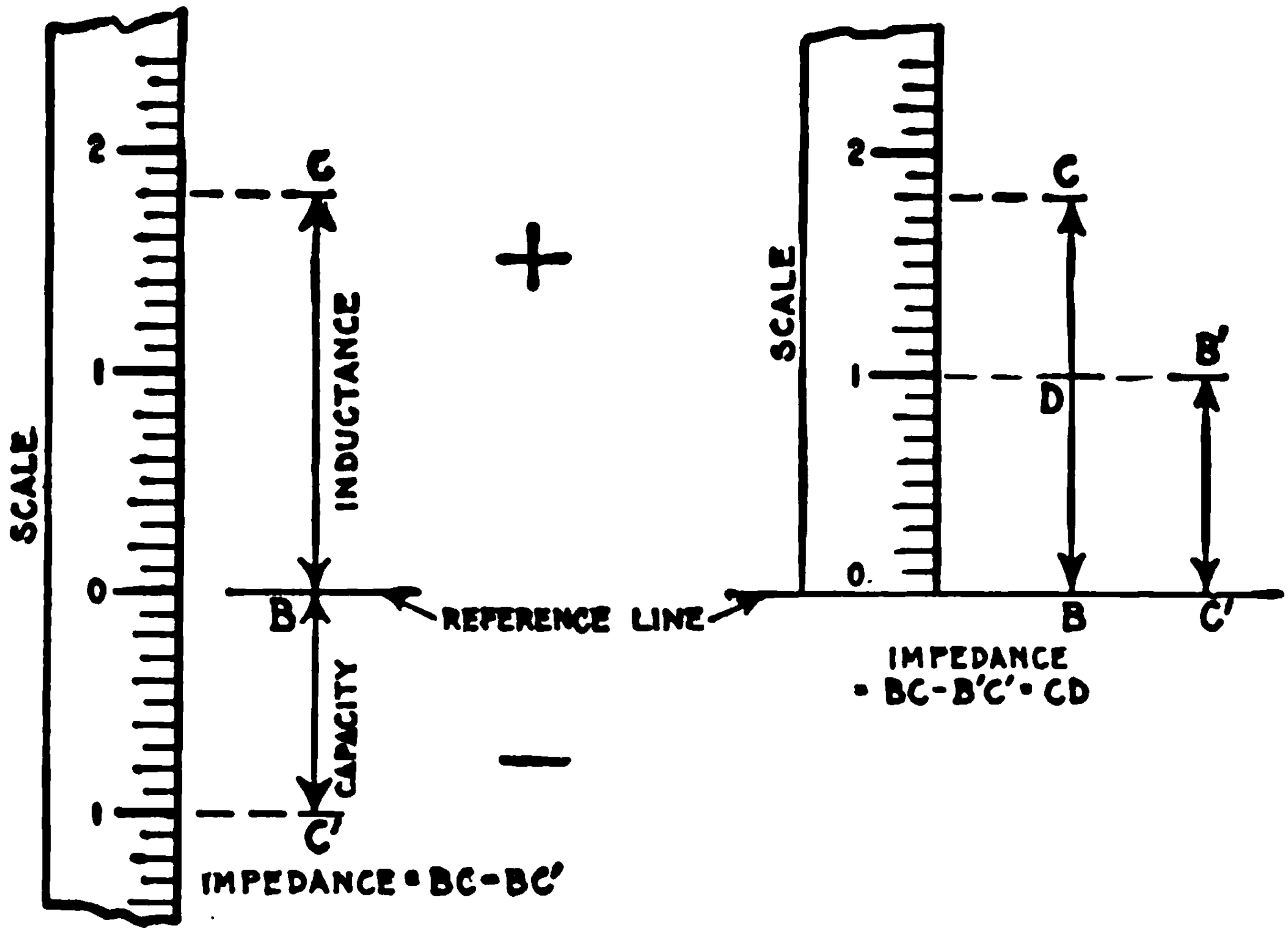
By calculation, *impressed pressure* = $\sqrt{240^2 + 170^2}$ = 294 volts.

EXAMPLE.—In the circuit shown in fig. 1,330, what is the angle of lead?

The tangent of the angle of lead is given by the quotient of the reactance divided by the resistance of the circuit. That is,

$$\tan\phi = \frac{\textit{reactance}}{\textit{resistance}} = \frac{\textit{reactance drop}}{\textit{resistance drop}}$$

$$\tan\phi = \frac{E_c}{E_a} = \frac{I}{2\pi f C} + E_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$



Figs. 1,332 and 1,333.—Diagrams for circuits containing inductance and capacity. Since inductance and capacity act 180° apart, their reactances, or their ohmic drops may be represented by oppositely directed lines. These may be drawn above and below a reference line, as in fig. 1,332, and their algebraic sum taken, or both may be drawn on the same side of the reference line and their difference in lengths, as CD, fig. 1,333, measured. Recourse to a diagram for obtaining the resultant reactance in circuits containing inductance and capacity is unnecessary as it is simply a matter of taking the difference of two quantities.

The tangent is given a negative sign because lead is opposed to lag and because the positive value is assigned to lag. Substituting in (1)

$$\tan\phi = \frac{170}{240} \text{ or } \frac{2.125''}{3''} = -.71$$

the angle corresponding is approximately 35¼° (see table page 451)

Circuits Containing Inductance and Capacity.—The effect of capacity in a circuit is exactly the opposite of inductance, that is, one tends to neutralize the other. The method of representing each graphically has been shown in the preceding figures. Since they act oppositely, that is 180° apart, the reactance due to each may be calculated and the values thus found, represented by oppositely directed vertical lines: the inductance resistance upward from a reference line, and the

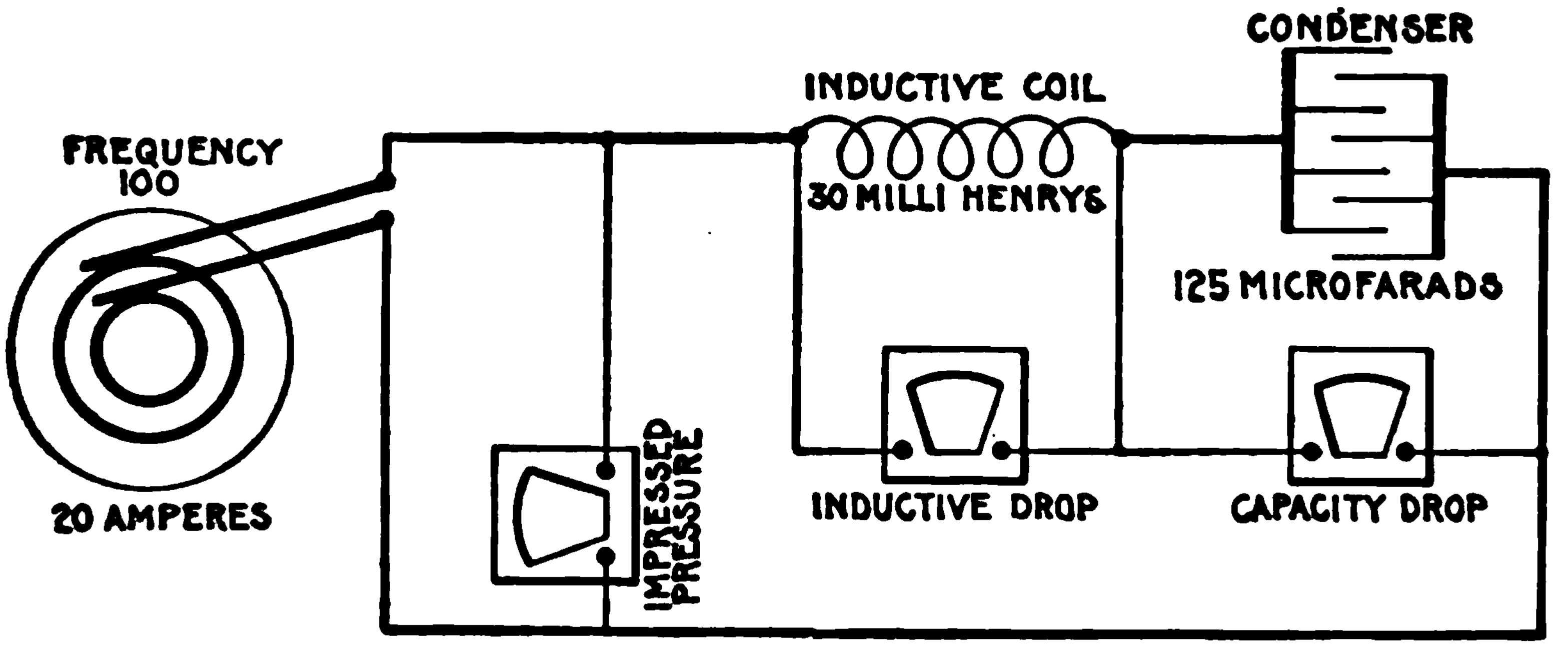


FIG. 1,334.—Diagram of circuit containing 30 millihenrys inductance and 125 microfarads capacity, with current of 20 amperes, 100 frequency.

capacity resistance downward from the same reference line. The difference then is the resultant impedance. This method is shown in fig. 1,332, but it is more conveniently done as in fig. 1,333.

EXAMPLE.—In a circuit, as in fig. 1,334, containing an inductance of 30 milli-henrys and a capacity of 125 microfarads, how many volts must be impressed on the circuit to produce a current of 20 amperes having a frequency of 100.

The inductance reactance is

$$X_i = 2\pi f L = 2 \times 3.1416 \times 100 \times .03 = 18.85 \text{ ohms.}$$

Substituting this and the current value of 20 amperes in the formula for inductance pressure

$$E_i = R_i I = 18.85 \times 20 = 377 \text{ volts.}$$

Reducing 125 microfarads to .000125 farad, and substituting in the formula for capacity pressure

$$E_c = \frac{I}{2\pi fC} = \frac{20}{2\times 3.1416\times 100\times .000125} = 255 \text{ volts.}$$

A diagram is unnecessary in obtaining the impressed pressure since it is simply the difference between inductance pressure and capacity pressure (the circuit being assumed to have no resistance), that is

$$\text{impressed pressure} = E_l - E_c = 377 - 255 = 122 \text{ volts.}$$

EXAMPLE.—A circuit in which a current of 20 amperes is flowing at a frequency of 100, has an inductance reactance of 18.25 ohms, and a capacity of 125 microfarads. What is the impedance?

The reactance due to capacity is

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\times 3.1416\times 100\times .000125} = 12.76 \text{ ohms.}$$

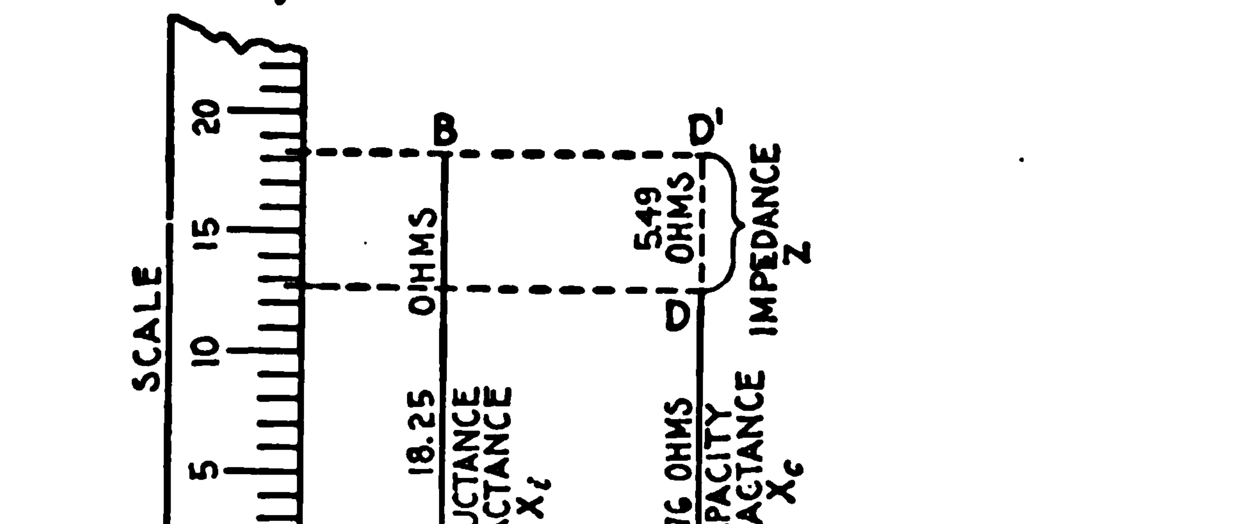


FIG. 1,335.—Impedance diagram for circuit (of above example) containing inductance and capacity. With any convenient scale, erect a perpendicular AB = 18.25 ohms, and CD = 12.76 ohms. Continue CD by dotted line to D' so that CD' = AB, then DD' = AB − CD = inductance reactance − capacity reactance, which is equal to the impedance. Expressed by letters $Z = X_l - X_c = DD'$, which by measurement = 5.49 ohms.

The impedance of the circuit then is the difference between the two reactances, that is impedance = inductance reactance − capacity reactance, or

$$Z = X_l - X_c = 18.25 - 12.76 = 5.49 \text{ ohms.}$$

Circuits Containing Resistance, Inductance, and Capacity.—When the three quantities resistance, inductance, and *capacity, are present* in a circuit, the combined effect is easily

understood by remembering that inductance and capacity always act oppositely, that is, they tend to neutralize each other. Hence, in problems involving the three quantities, the resultant of inductance and capacity is first obtained, which, together with the resistance, is used in determining the final effect.

Capacity introduced into a circuit containing inductance reduces the latter and if enough be introduced, inductance will be neutralized, giving a resonant circuit which will act as though only resistance were present.

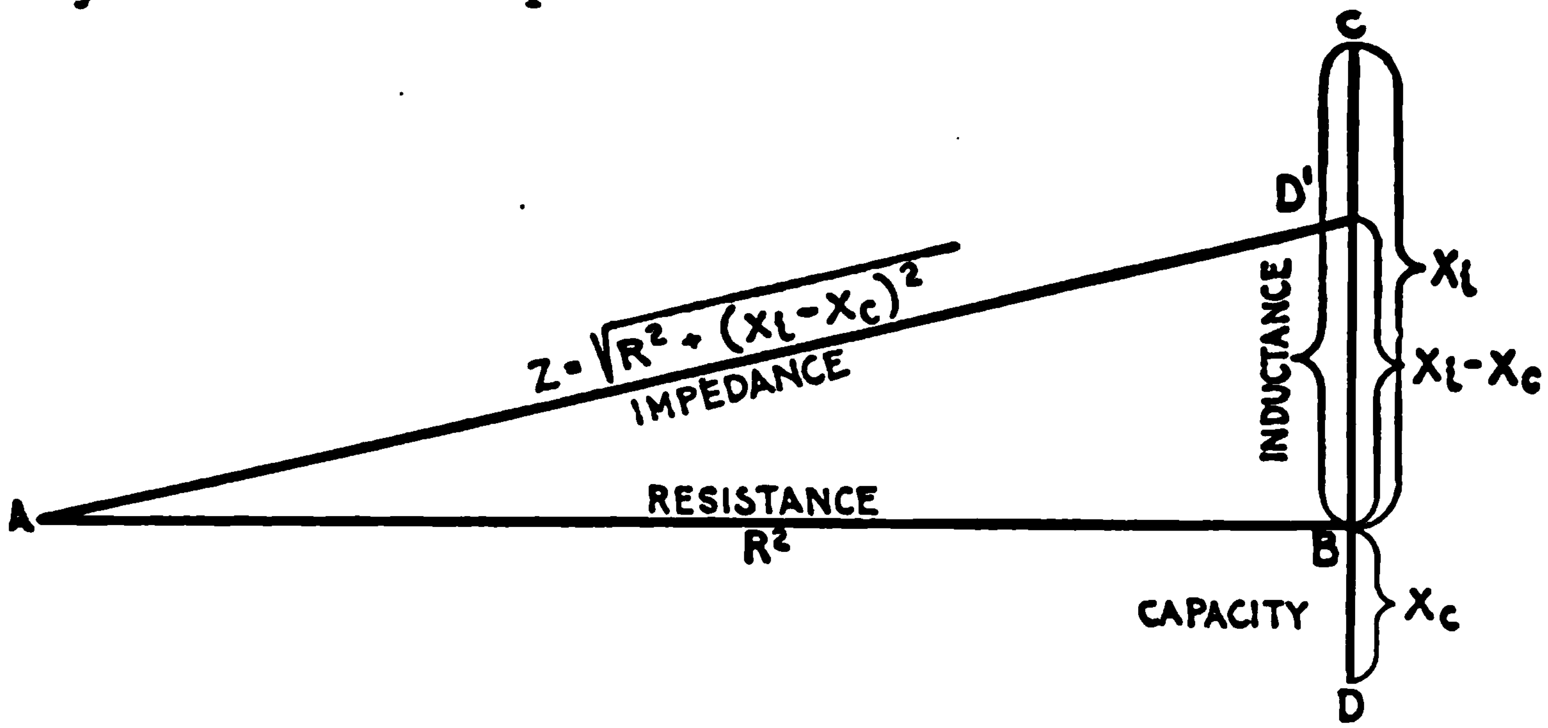


FIG. 1,336.—Impedance diagram for circuit containing resistance, inductance and capacity. The symbols correspond to those used in equation (1) below. In constructing the diagram from the given values, lay off AB = resistance; at B, draw a line at right angles, on which lay off above the resistance line, BC = inductive reactance, and below, BD = capacity reactance, then the resultant reactance = BC − BD = BD′. Join A and D′, then AD′ = impedance.

Ques. What is the expression for impedance of a circuit containing resistance, inductance and capacity?

Ans. It is equal to *the square root of the sum of the resistance squared plus the square of inductance reactance minus capacity reactance.*

This is expressed plainer in the form of an equation as follows:

impedance = $\sqrt{\textit{resistance}^2 + (\textit{inductance reactance} - \textit{capacity reactance})^2}$

or, using symbols,

$$Z = \sqrt{R^2 + (X_l - X_c)^2} \quad \ldots\ldots\ldots\ldots (1)$$

Ques. If the capacity reactance be larger than the inductance reactance, how does this affect the sign of $(X_i - X_c)^2$?

Ans. The sign of the resultant reactance of inductance and capacity will be negative if capacity be the greater, but since in the formula the reactance is squared, the sign will be positive.

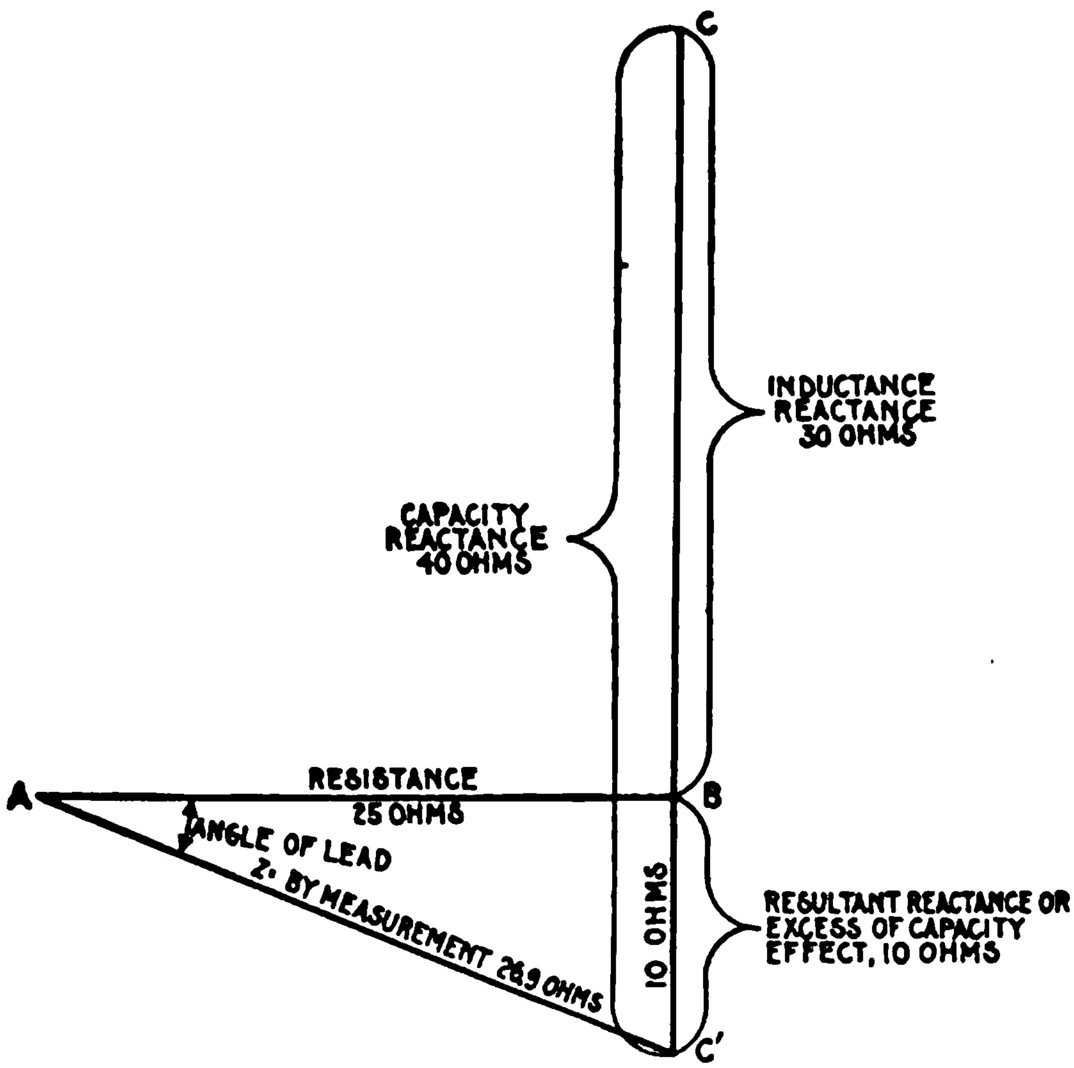


FIG. 1,337.—Impedance diagram of a circuit containing 25 ohms resistance, 30 ohms inductance, and 40 ohms capacity. The resultant reactance being due to excess of capacity, the impedance line AC′ falls *below* the horizontal line AB, indicating that the current *leads* pressure.

EXAMPLE.—What is the impedance in a circuit having 25 ohms resistance, 30 ohms inductance reactance, and 40 ohms capacity reactance?

To solve this problem graphically, draw the line AB, in fig. 1,337, equal to 25 ohms resistance, using any convenient scale.

At B draw upward at right angles BC = 30 ohms; draw from C downward CC′ = 40 ohms. This gives −BC′ (= BC − CC′) showing the capacity reactance to be 10 ohms in excess of the inductance reactance. Such a

[redacted]

circuit is equivalent to one having no inductance but the same resistance and 10 ohms capacity reactance.

The diagram is completed in the usual way by joining AC giving the required impedance, which by measurement is 26.9 ohms.

By calculation, $Z = \sqrt{25^2+(30-40)^2} = \sqrt{25^2+(-10)^2} = 26.9.$

Form of Impedance Equation without Ohmic Values.—

Using the expressions $2\pi fL$ for inductance reactance and $\frac{1}{2\pi fC}$

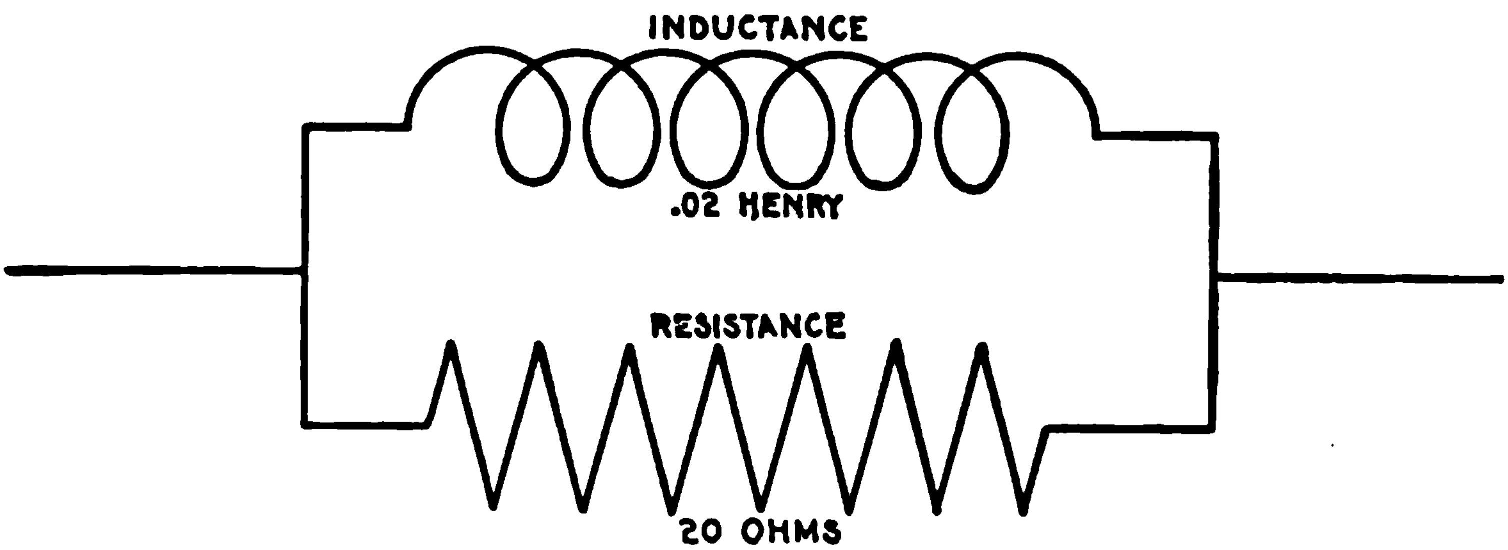


FIG. 1,338.—EXAMPLE: A resistance of 20 ohms and an inductance of .02 henry are connected in parallel as in the diagram. What is the impedance, and how many volts are required for 50 amperes, when the frequency is 78.6? SOLUTION: The time constants are not alike, hence the geometric sum of the reciprocals must be taken as the reciprocal of the required impedance. That is, the combined conductivity will be the hypothenuse of the right triangle, of which the ohmic conductivity and the reactive conductivity are the two sides, respectively. Accordingly: $\frac{1}{R} = \frac{1}{20} = .05$, and $\frac{1}{2\pi fL} = \frac{1}{10} = .1$, from which, $\frac{1}{R} = \sqrt{\left(\frac{1}{R_1}\right)^2+\left(\frac{1}{2\pi fL}\right)^2} = .111$. Whence $Z = \frac{1}{.111} = 9$ ohms.

for capacity reactance, and substituting in equation (1) on page 1,093 gives the following:

$$Z = \sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2} \quad \text{.............} \quad (2)$$

which is the proper form of equation (1) to use in solving problems in which the ohmic values of inductance and capacity must be calculated.

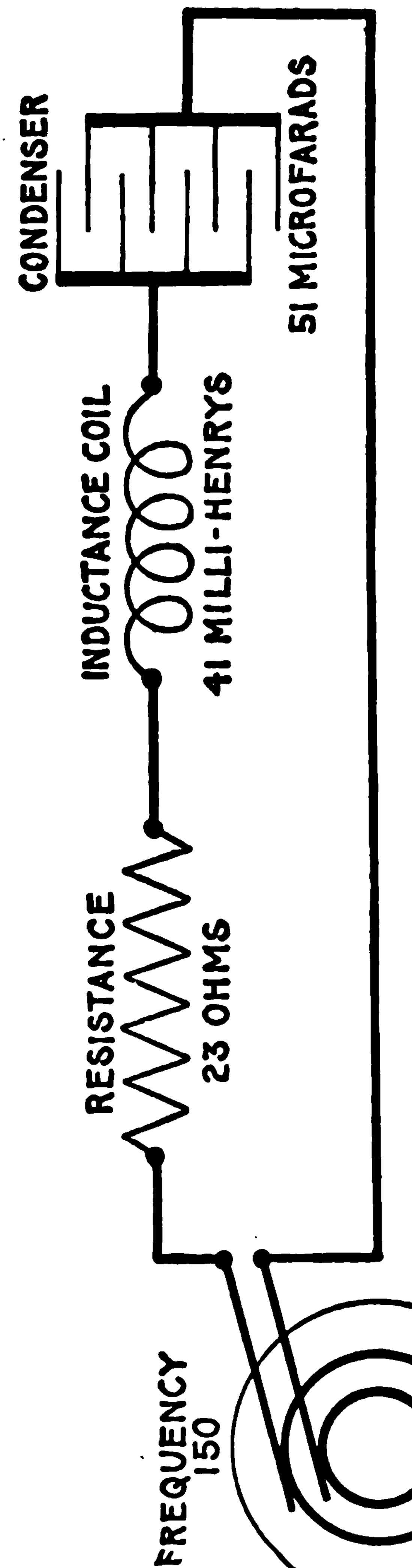


FIG. 1,339.—Diagram of circuit containing 23 ohms resistance, 41 millihenrys inductance, and 51 microfarads capacity, with current supplied at a frequency of 150.

EXAMPLE.—A current has a frequency of 150. It passes through a circuit, as in fig. 1,339, of 23 ohms resistance, of 41 millihenrys inductance, and of 51 microfarads capacity. What is the impedance?

The inductance reactance or

$$X_i = 2\pi f L = 2 \times 3.1416 \times 150 \times .041$$
$$= 38.64 \text{ ohms}$$

(note that 41 henrys are reduced to .041 henry before substituting in the above equation).

The capacity reactance, or

$$X_c = \frac{1}{2\pi f C} =$$

$$\frac{1}{2 \times 3.1416 \times 150 \times .000051} = 20.8 \text{ ohms}$$

(note that 51 microfarads are reduced to .000051 farad before substituting in the above equation).

Substituting the values as calculated

for $2\pi f L$ and $\frac{1}{2\pi f C}$ in equation (2)

$$Z = \sqrt{23^2 + (38.64 - 20.8)^2} = 29.1 \text{ ohms.}$$

To solve the problem graphically, lay off in fig. 1,340, the line AB equal to 23 ohms resistance, using any convenient scale. Draw upward and at right angles to AB the line BC = 38.64 ohms inductance reactance, and from C lay off downward CC′ = 20.8 ohms capacity reactance. The resultant reactance

is BC′ and being above the horizontal line AB shows that inductance reactance is in excess of capacity reactance by the amount BC′. Join AC′ which gives the impedance sought, and which by measurement is 29.1 ohms.

In order to obtain the **impressed pressure in circuits containing resistance, inductance and reactance,** an equation similar to (2) on page 1,095 is used which is made up from the following:

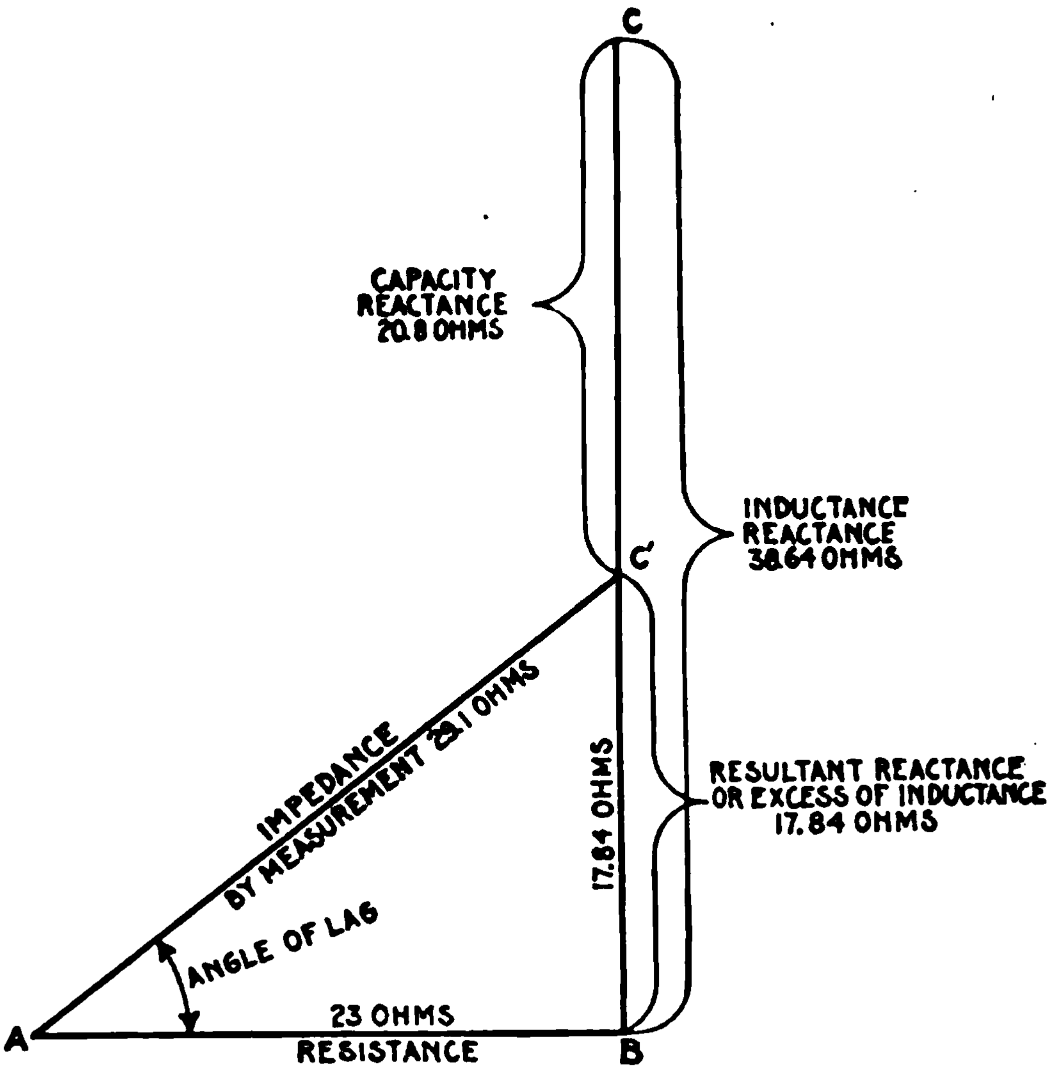


FIG. 1,340.—Impedance diagram for the circuit shown in fig. 1,339. Note that the resultant reactance being due to excess of inductance, the impedance line AC′ falls *above* the horizontal line AB. This indicates that the current *lags* behind the pressure.

$$E_o = RI \qquad (3)$$

$$E_i = 2\pi f LI \qquad (4)$$

$$E_c = \frac{I}{2\pi f C} \qquad (5)$$

When all three quantities, resistance, inductance, and capacity are *present, the equation* is as follows:

$$\textit{impressed pressure} = \sqrt{\textit{ohmic drop}^2 + (\textit{inductive drop} - \textit{capacity drop})^2}$$

$$E_{im} = \sqrt{E_o^2 + (E_i - E_c)^2} \ldots\ldots\ldots\ldots\ldots (6)$$

Substituting in this last equation (6), the values given in (3), (4) and (5)

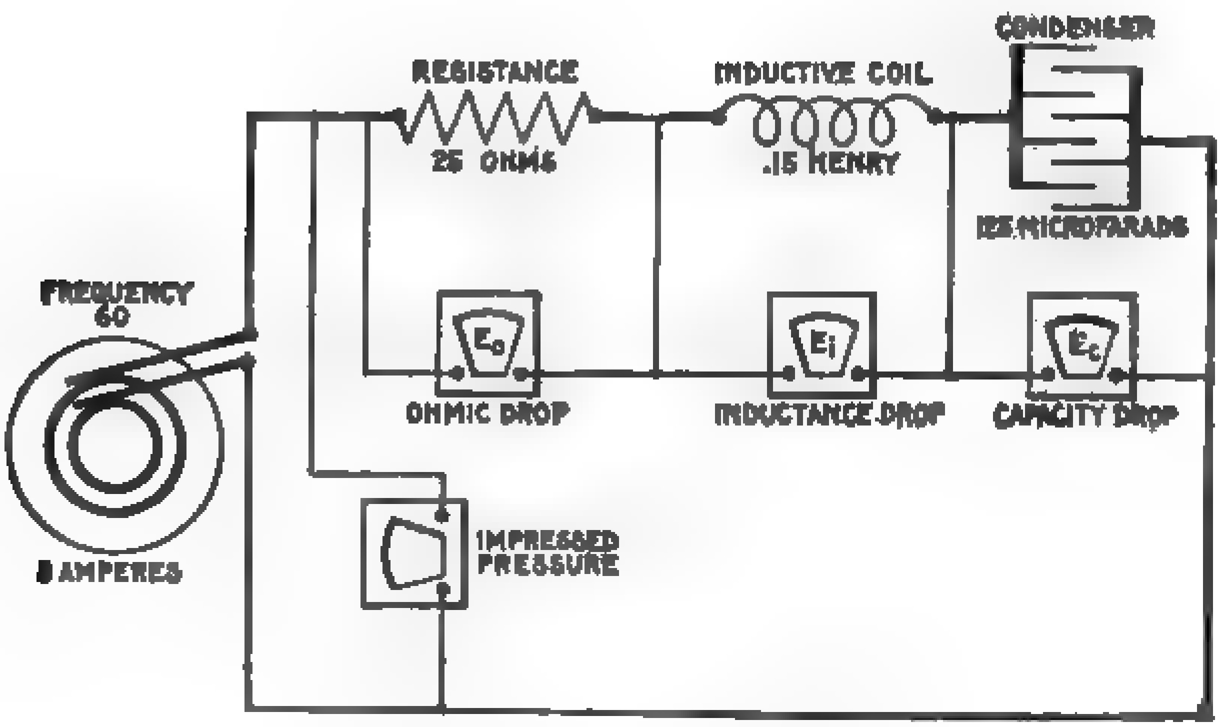


FIG. 1,341.—Diagram of circuit containing 25 ohms resistance, .15 henry inductance, and 125 microfarads capacity, with current of 8 amperes at 60 frequency.

$$E_{im} = \sqrt{R^2 I^2 + \left(2\pi f LI - \frac{I}{2\pi f C}\right)^2}$$

$$= I \sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2} \ldots\ldots\ldots (7)$$

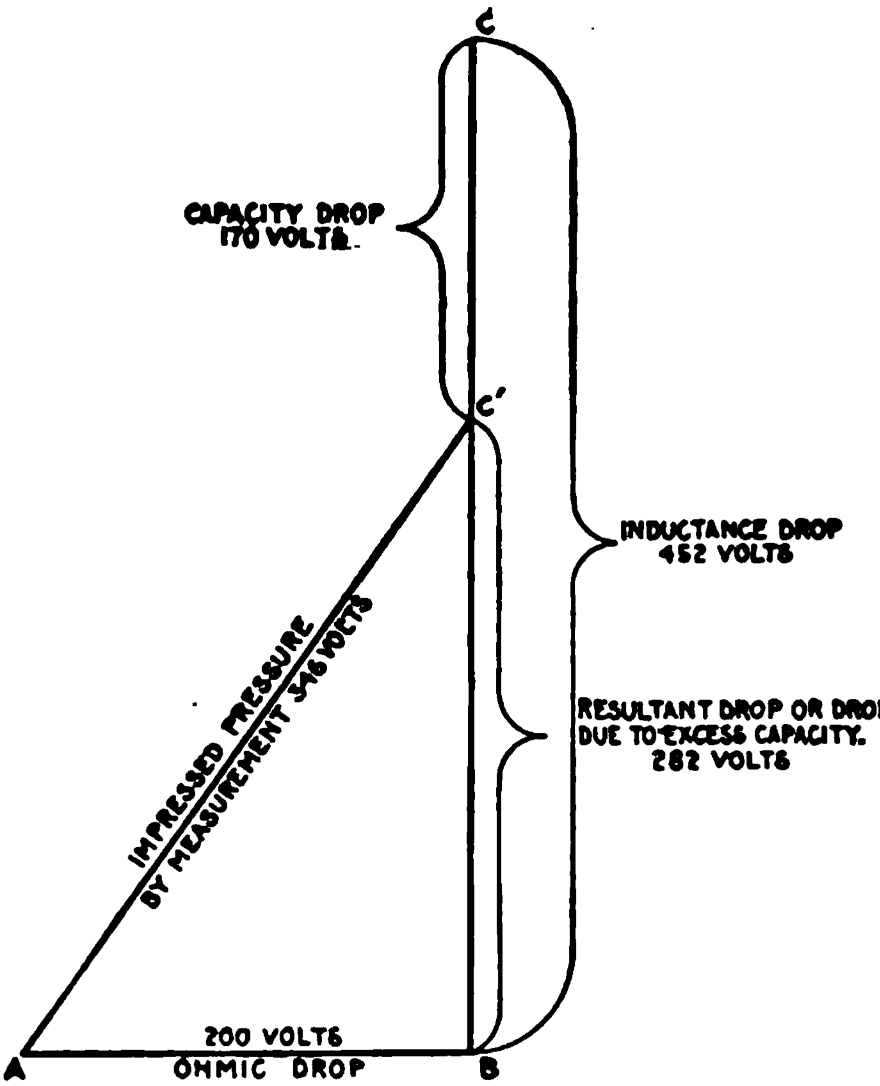
Ques. What does the quantity under the square root sign in equation (7) represent?

Ans. It is the impedance of a circuit possessing resistance, inductance, and capacity.

ues. Why?

ıs. Because it is that quantity which multiplied by the ənt gives the pressure, which is in accordance with Ohm's

EXAMPLE.—An alternator is connected to a circuit having, as in fig. 1,341, 25 ohms resistance, an inductance of .15 henry, and a capacity of 125 microfarads. What pressure must be impressed on the circuit to allow 8 amperes to flow at a frequency of 60?



.342.—Diagram for finding the pressure necessary to be impressed on the circuit shown ı fig. 1,341, to produce a current of 8 amperes.

The ohmic drop is

$$E_o = RI = 25 \times 8 = 200 \text{ volts.}$$

The inductance drop is

$$E_l = 2\pi f LI = 2 \times 3.1416 \times 60 \times .15 \times 8 = 452 \text{ volts}$$

The capacity drop is

$$E_c = \frac{I}{2\pi f C} = \frac{8}{2 \times 3.1416 \times 60 \times .000125} = 170 \text{ volts.}$$

Substituting the values thus found,

$$\text{impressed pressure} = \sqrt{E^2_o + (E_i - E_c)^2}$$

$$= \sqrt{200^2 + (452 - 170)^2}$$

$$= \sqrt{200^2 + 282^2}$$

$$= \sqrt{119524}$$

$$= 345.7 \text{ volts.}$$

CHAPTER XLVIII

THE POWER FACTOR

The determination of the power in a direct current circuit is a simple matter since it is only necessary to multiply together the volts and amperes to obtain the output in watts. In the case of alternating current circuits, this holds true only when the current is in phase with the pressure—a condition rarely found in practice.

When the current is not in phase with the pressure, the product of volts and amperes as indicated by the voltmeter and ammeter must be multiplied by a coefficient called the *power factor* in order to obtain the *true watts*, or actual power available.

There are several ways of defining the power factor, any of which requires some explanation. The power factor may be defined as: *The number of watts indicated by a wattmeter, divided by the apparent watts*, the latter being the *watts as measured by a voltmeter and ammeter.*

The power factor may be expressed as being equal to

$$\frac{\textit{true power}}{\textit{apparent power}} = \frac{\textit{true watts}}{\textit{apparent watts}} = \frac{\textit{true watts}}{\textit{volts} \times \textit{amperes}}$$

Ques. What are the true watts?

Ans. The watts as measured by a wattmeter.

Ques. What are the apparent watts?

Ans. The watts obtained by multiplying together the simultaneous voltmeter and ammeter readings.

Ques. What is usually meant by power factor?

Ans. The multiplier used with the apparent watts to determine how much of the power supplied is available.

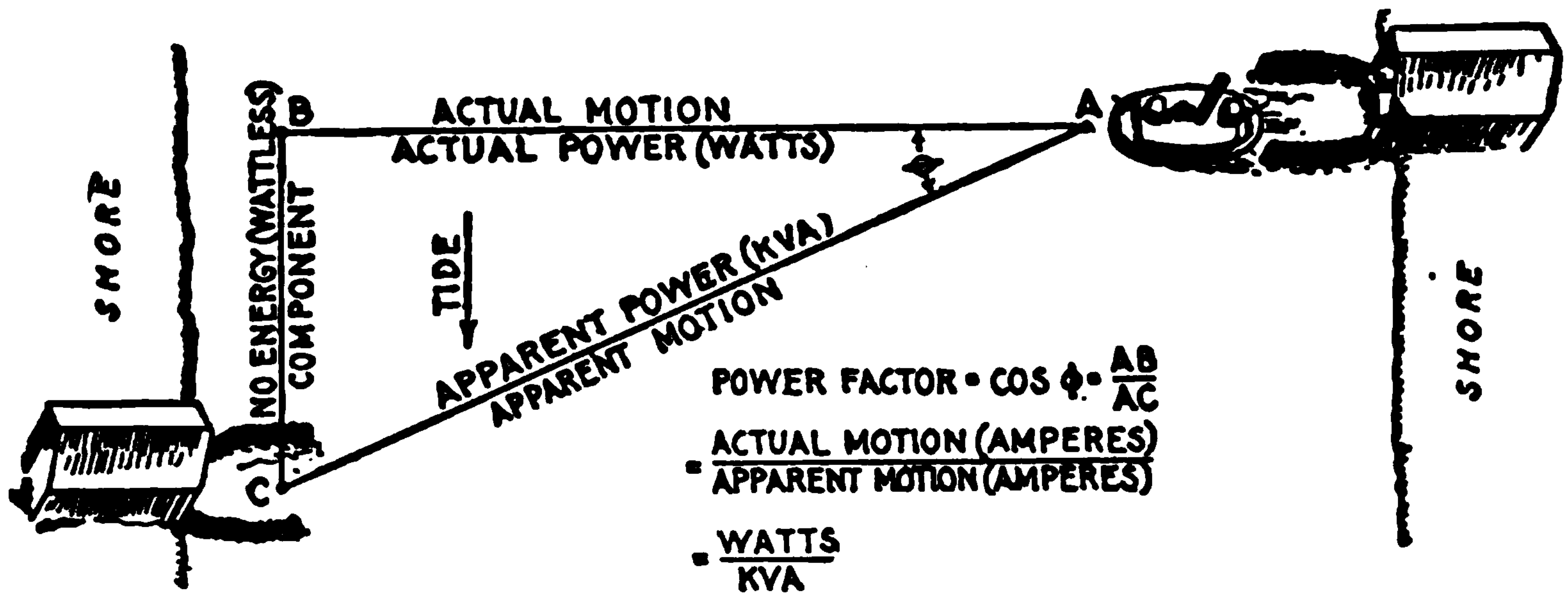


FIG. 1,343.—Marine analogy of power factor. A ferry boat in crossing a river to a slip C would head for some point B up stream from C to allow for the effect of the tide. Under such conditions the actual motion (referred to the water) would be from A to B, and the apparent motion, from A to C. Accordingly, the energy expended in propelling the boat from A to B in still water, will propel it from A to C when the tide is running in the direction of the arrow. The effect of the tide is the same as that of inductance or capacity in an alternating circuit, that is, it puts the applied force or thrust (impressed volts) out of phase with the motion of the boat (amperes), this phase difference being indicated by the angle BAC or ϕ. Now, *work* (watts) is the product of two factors, pressure (volts) and distance (amperes); accordingly, the apparent work done in propelling the boat from A to C is the product of the *thrust of the paddle wheels multiplied by* AC, which in analogy corresponds to the product of voltmeter and ammeter readings at the alternator, called "kva." Actually, however, the power is only applied from A to B, the boat being carried sidewise by the tide, as it crosses, a distance BC which represents no energy expended by the paddle wheels. In analogy, the actual power, expended in propelling boat from A to B corresponds to the wattmeter reading in an alternating current power circuit. To obtain the actual work done on the boat, the product of its apparent motion × thrust must be multiplied by a coefficient or *power factor* because the thrust is applied at an angle to the apparent motion, the power factor being equal to the cosine of this angle, (ϕ) or AB ÷ AC. Similarly, when there is phase difference between pressure and alternating current, the voltmeter and ammeter readings must be multiplied by the power factor or cos ϕ to give the output of an alternator available for external work, the excess power indicated by ammeter and voltmeter readings, performing no external work, but causing objectionable heating of the alternator.

Ques. Upon what does the power factor depend?

Ans. Upon the relative amounts of resistance inductance and capacity contained in the circuit.

Ques. How does the power factor vary in value?

Ans. It varies from one to zero.

The power factor, as will be shown later, is equal to *the cosine of the angle of phase difference;* its range then is from one to zero because these are the limiting values of the cosine of an angle (neglecting the + or − sign).

Ques. What is the effect of lag or lead of the current on the power factor?

And. It causes it to become less than one.

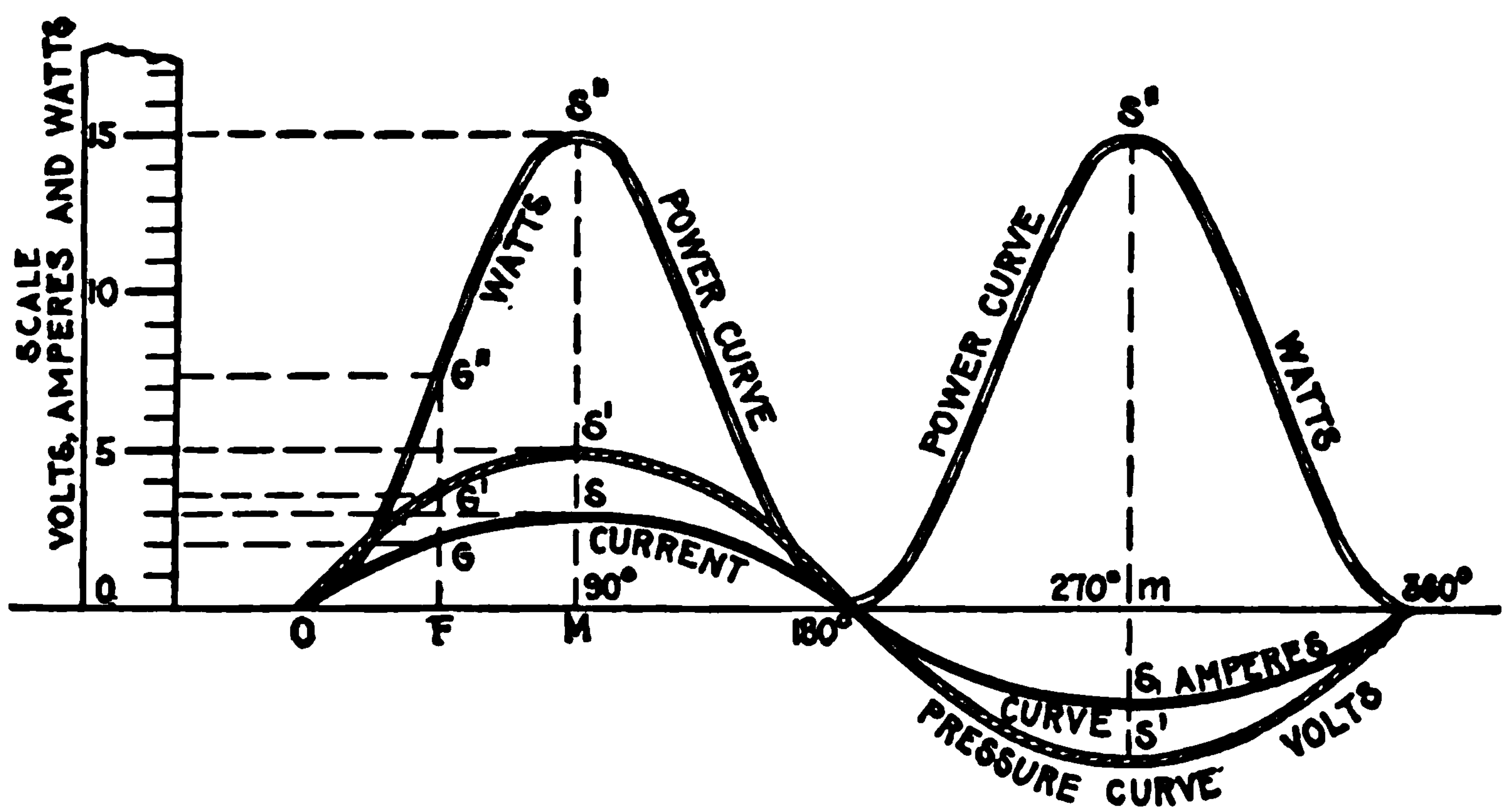


FIG. 1,344.—Method of drawing the power curve from the pressure and current curves. As shown, the same scale is used for all curves. This as a rule, makes the power curve inconveniently high, hence it is usually drawn to smaller scale as in fig. 1,345.

How to Obtain the Power Curve.—Since under any phase condition, the power at any instant is equal to the product of the pressure multiplied by the current at that instant, a curve may be easily plotted from the pressure and current curves, giving the *instantaneous values of the power* through a complete cycle.

In fig 1,344, from the zero line of the current and pressure curves, *draw any ordinate as at F* cutting the current curve at G and the pressure

curve at G'. The values for current and pressure at this point are from the scale, 2 amperes and 3.7 volts. Since watts = amperes × volts, the ordinate FG is to be multiplied by ordinate FG' that is,

$$2 \times 3.7 = 7.4.$$

Project up through F the ordinate FG'' = 7.4, and this will give one point on the power curve.

Similarly at another point, say M, where the current and pressure are maximum

$$\begin{array}{ccccl} MS & \times & MS & = & MS'', \text{ that is} \\ 3 & \times & 5 & = & 15 \end{array}$$

giving S'' another point on the curve. Obtaining several points in this way the power curve is then drawn through them as shown.

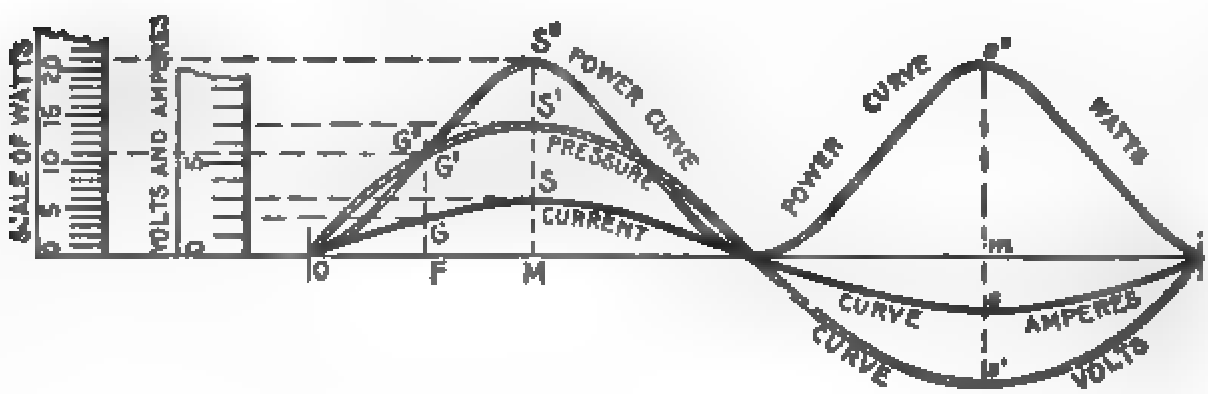


FIG. 1,345.—Usual method of drawing power curve from the pressure and current curves. A smaller scale is employed for the power curve in order to reduce its height.

Ques. Why is the power curve positive in the second half of the period when there are negative values of current and pressure?

Ans. Because the product of two negative quantities is positive.

Ques. Does fig. 1,344 represent the usual way of drawing a power curve?

Ans. Since ordinates of the power curve are products of the current and pressure ordinates, they will be of inconvenient

length if drawn to the same scale; it is therefore customary to use a different scale for the power ordinates, as in fig. 1,345.

The illustration is lettered identical with fig. 1,344, with which it should be compared.

Synchronism of Current and Pressure; Power Factor Unity.—The current and pressure would be in phase as represented in fig. 1,346 were it possible to have a circuit contain-

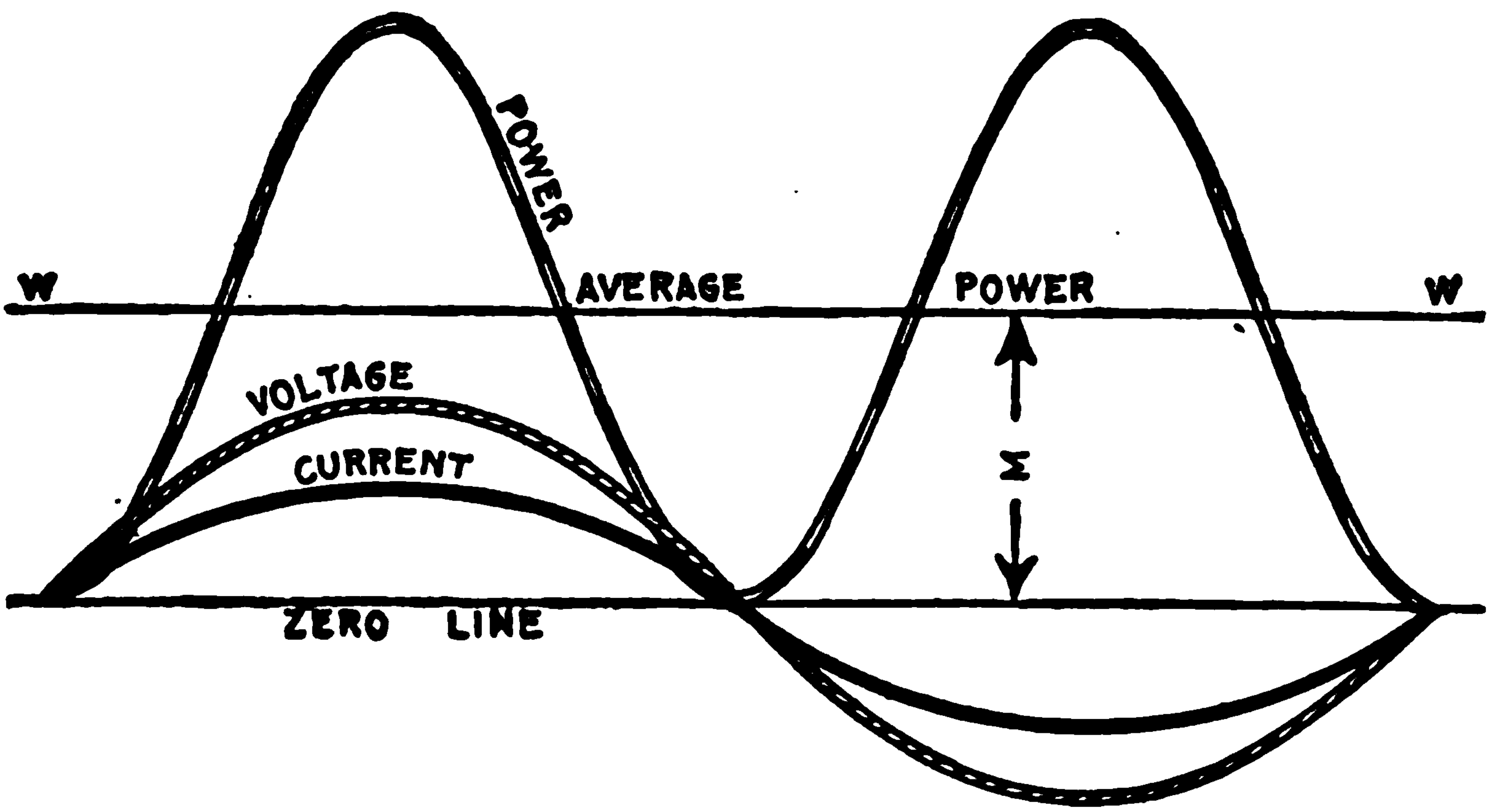


FIG. 1,346.—Synchronism of current and pressure. Power curve showing that the power factor is unity. This is indicated by the fact that the power curve does not project below the base or zero line.

ing resistance only. In actual practice all circuits contain at least a small amount of reactance.

A circuit supplying nothing but incandescent lamps comes very nearly being all resistance, and may be so considered in the discussion here. Fig. 1,347 illustrates a circuit containing only resistance. In such a circuit the pressure and current (as shown in fig. 1,346) pass through zero and through their maximum values together.

Multiplying instantaneous values of volts and amperes will give the power curve, as before explained, whose average value is half-way between the zero line and the maximum of the curve; that part of the power curve above the line of average power WW, exactly filling the open space below the line WW. That is,

$$\text{average power} = \text{maximum power} \div \sqrt{2}$$

$$= \frac{\text{maximum voltage} \times \text{maximum current}}{\sqrt{2}}$$

$$= \text{virtual voltage} \times \text{virtual current.}$$

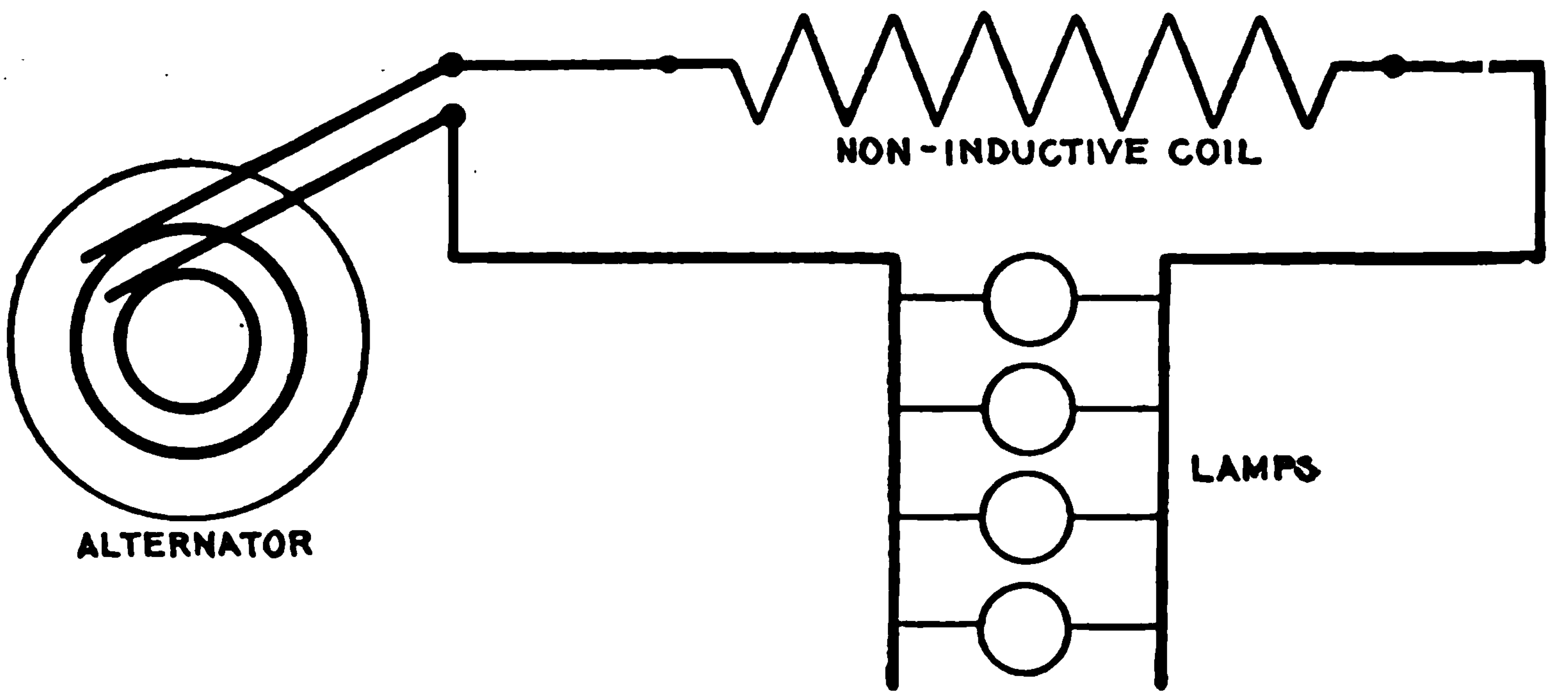


Fig. 1,347.—Diagram of circuit containing only resistance; in such a circuit the power factor is unity.

This latter is simply the product of the voltmeter and ammeter readings which gives the watts just the same as in direct current.

Ques. What should be noticed about the power curve?

Ans. Its position with respect to the zero line; it lies wholly above the zero line which denotes that all the power delivered to *the circuit* except that dissipated by friction is useful, that is, the

power factor is unity. Hence, *to keep the power factor as near unity as possible is one of the chief problems in alternating current distribution.*

Ques. Can the power factor be less than unity if the current and pressure be in phase?

Ans. Yes, if the waves of current and voltage be distorted as in fig. 1,348.

Effect of Lag and Lead.—In an alternating circuit the amount of power supplied depends on the phase relationship of the current and pressure. As just explained, when there is

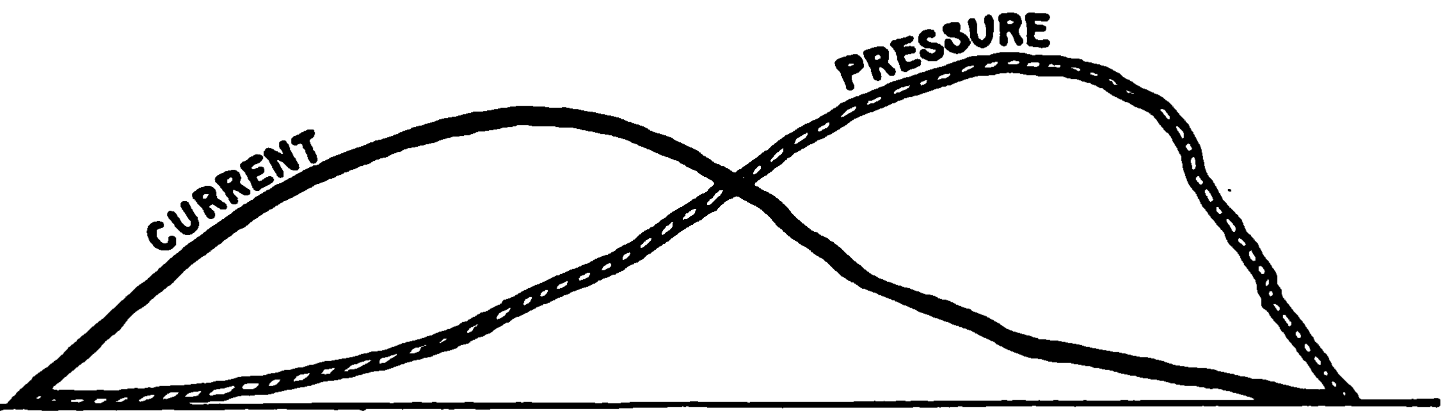


FIG. 1,348.—Case of synchronism of current and pressure with power factor less than unity. Suppose the waves of current and voltage to be in phase, but distorted in form, and not symmetrical, so that they do not run uniformly together, as shown in the figure. Then the real power factor may not be unity, although indicated as such by the power factor meter. However, the switchboard instruments are made to show the angle of lag as the power factor, because the error due to wave distortion is generally too small to be considered.

synchronism of current and pressure, that is, when they are in phase (as in fig. 1,346) the power factor is unity, assuming no distortion of current and pressure waves. In all other cases the power factor is less than unity that is, *the effect of lag or lead is to make the power factor less than unity.*

The effect of lag on the power factor may be illustrated by fig. 1,349, in which the angle between the pressure and current, or the angle of lag is taken as 40°, corresponding to a power factor of .766. *Plotting the* power curve from the products

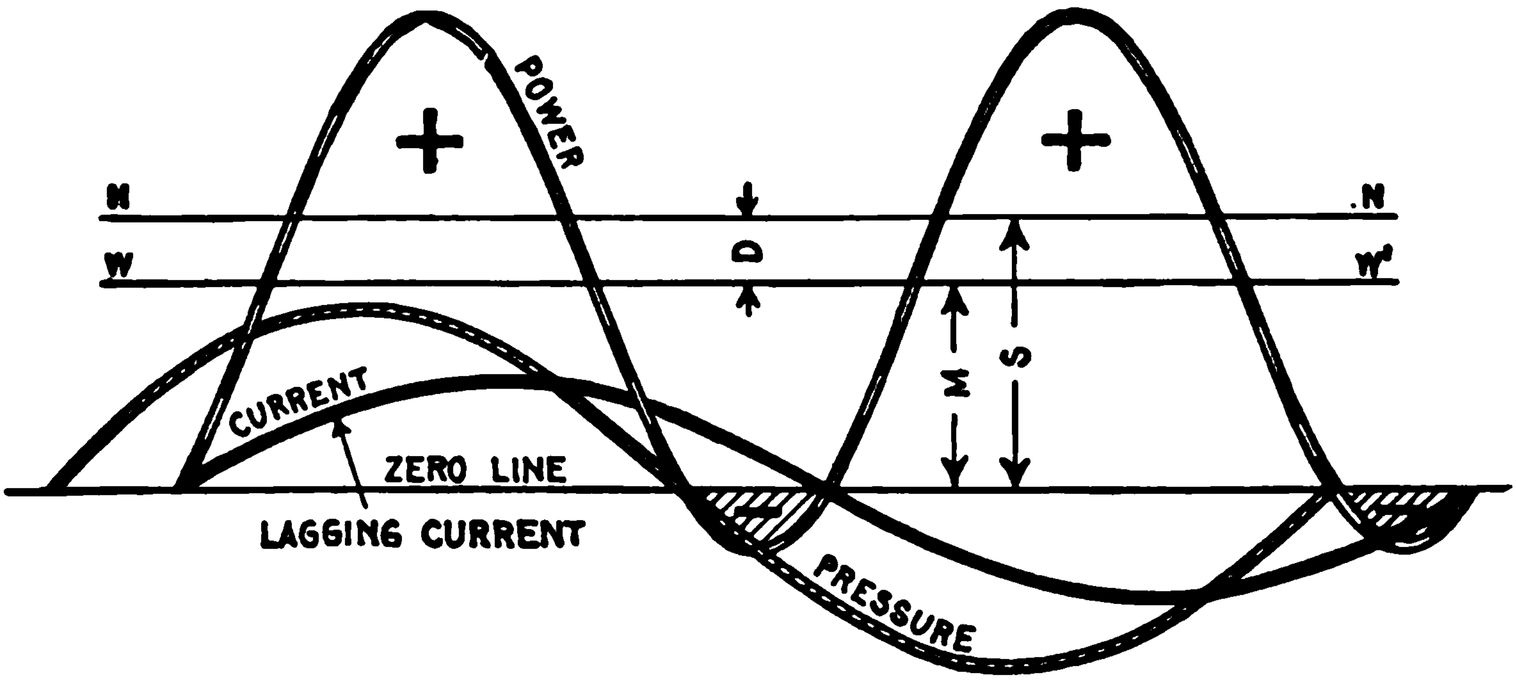


FIG. 1,349.—Effect of lag on the power factor. When the current lags behind the pressure the power factor becomes less than unity. It will be seen that the power curve projects below the zero line giving the shaded area which represents negative power which must be subtracted from the + areas above the zero line to get the net power. In the figure the line WW' is drawn at a height corresponding to the average power, and HN at a height corresponding to the average power that would be developed if the current were in phase with the pressure. The power factor then is represented by M + S, and by inspection of the figure it is seen that this is less than unity.

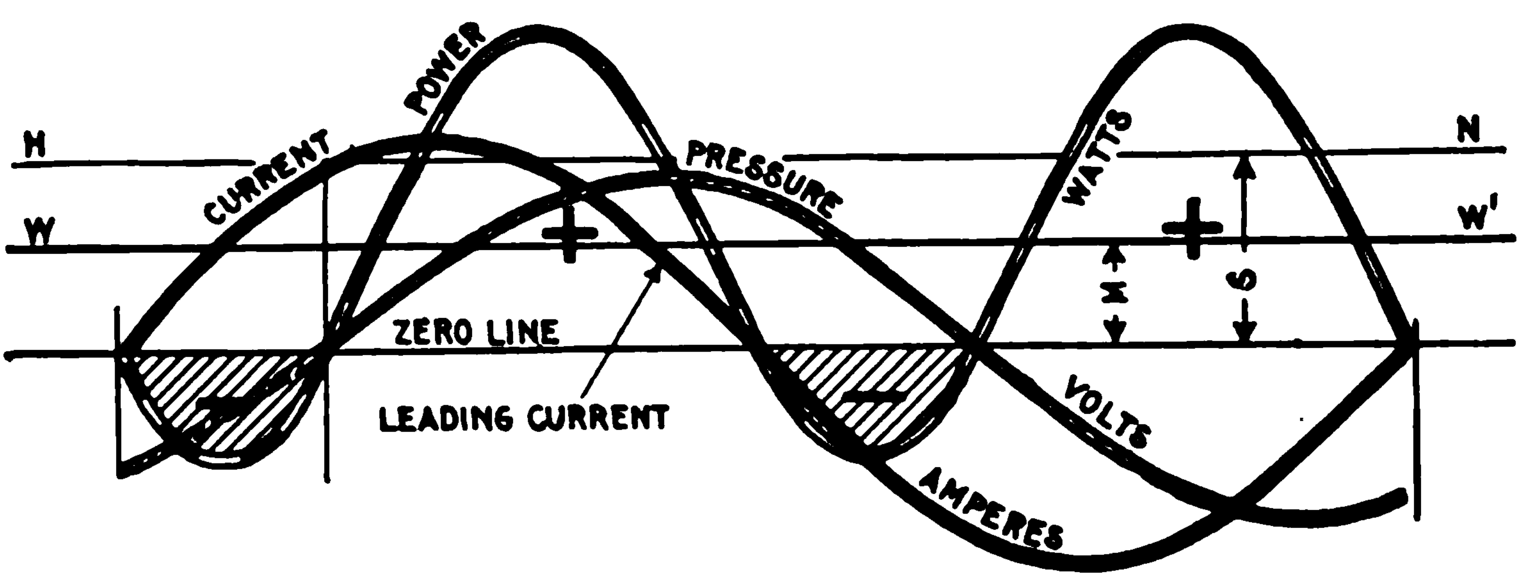


FIG. 1,350.—Effect of lead on the power factor. When the current is in advance of the pressure the power factor becomes less than unity. The curve, as shown, projects below the zero line, giving the shaded area which represents negative power which must be subtracted from the + areas above the zero line to get the net power. As in fig. 1,349, the line WW' at a height M represents the average power, and HN the average power for *synchronism of current* and pressure. The power factor then is M + S which is less *than unity.*

of instantaneous volts and amperes taken at various points, the power curve is obtained, a portion of which lies below the horizontal line. The significance of this is that at certain times, the current is flowing in the opposite direction to that in which the impressed pressure would send it. During this part of the period

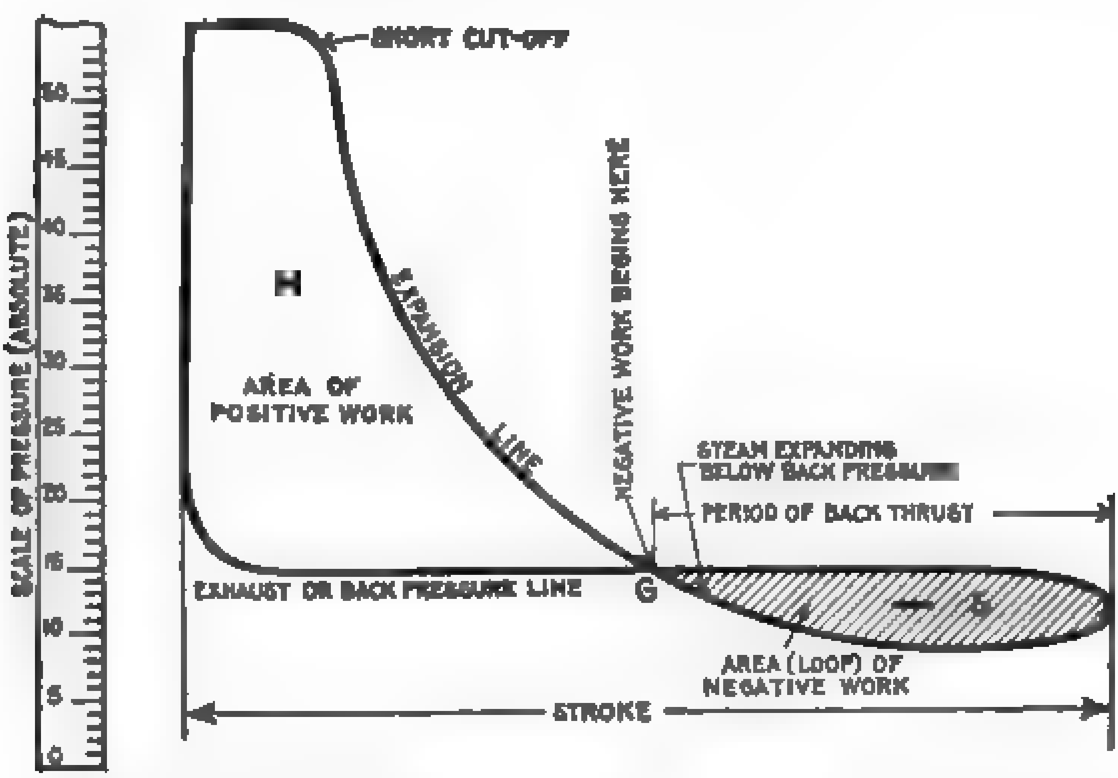


FIG. 1,351 Steam engine analogy of power factor. The figure represents an indicator card of an engine in which the steam distribution is such that the steam is expanded below the back pressure line, that is below the pressure of the exhaust. This results in *negative work* which must be overcome by the *momentum* or *kinetic energy* previously stored in the fly wheel, and which is represented on the diagram by the shaded loop S. If the exhaust valve had opened at G, the amount of work done during the revolution would be represented by the area M, but continuing the expansion below the back pressure line, the work done is M − S. This latter case as compared with the first when expansion does not continue below the back pressure line gives an efficiency (power factor) of (M − S) ÷ M, the shaded area representing so much loss.

conditions are reversed, and the power (indicated by the shaded area), instead of being supplied by the source to the circuit, is being supplied by the circuit to the source.

This condition is exactly analogous to the case of a steam engine, expanding the steam below the back or exhaust pressure, a condition sometimes caused *by the action of* the governor in considerably reducing

the cut off for very light load. An indicator diagram of such steam distribution is shown in fig. 1,351. This gives a negative loop in the diagram indicated by the shaded section.

It must be evident that the average pressure of the shaded loop portion of the diagram must be subtracted from that of the other portion, because during the expansion below the exhaust pressure line, the back pressure is in excess of the forward pressure exerted on the piston by the expanding steam, and the engine would accordingly reverse its motion, *were it not for the energy previously stored up in the fly wheel* in the form of *momentum*, which keeps the engine moving during this period of back thrust. Evidently the shaded area must be subtracted from

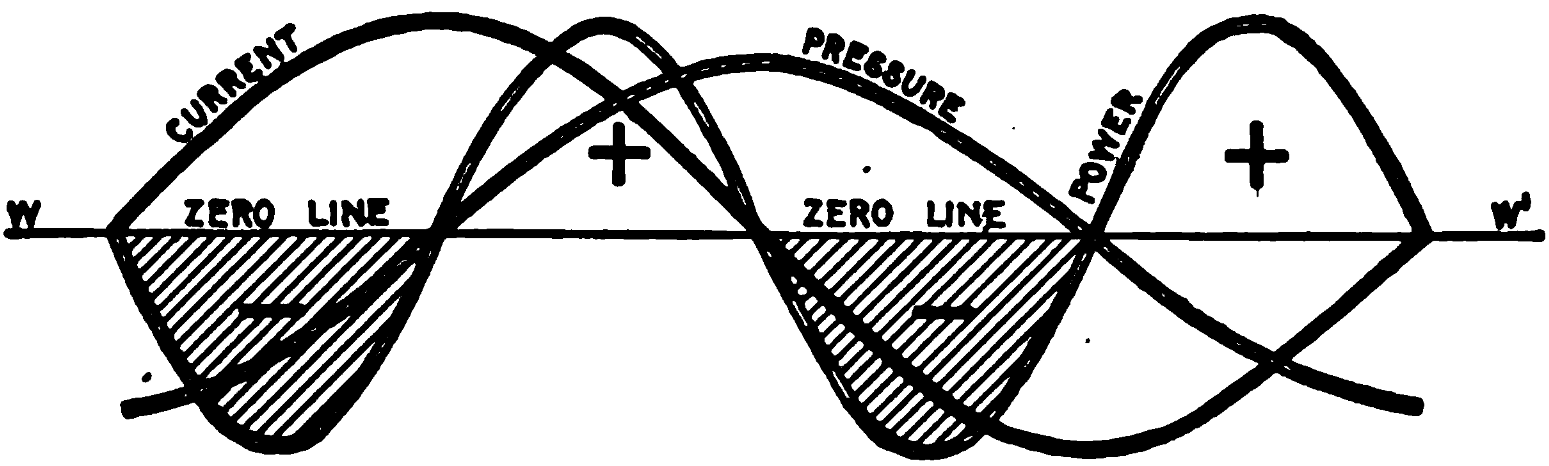


FIG. 1,352.—Power curve illustrating the so-called wattless current in which case the power factor is zero. By noting that the curve projects equally on each side of the zero line, the + power areas equal the negative power areas, hence the summation of these areas for the period is zero, that is, the two + areas minus the two shaded areas equal zero. It should be noted that the line of average power WW', which is visible in the other figures, here coincides with the zero line, and the average power then is zero, since the positive part above the zero line is equal to and offsets the negative (shaded) part below the line. This is the case of "wattless" current and (considering a circuit with resistance so small that it may be considered as zero) shows plainly the possibility of having full load current and voltage on a circuit yet delivering no power, the current simply surging to and fro without an actual transfer of power.

the positive area to obtain the net work done during the stroke. Hence following the analogy as far as possible if M work (watts) be done during each revolution (cycle) when steam does not expand below back pressure (when current and pressure are in phase), and S negative work (negative watts) be done when steam expands below back pressure (when there is lag), the efficiency (power factor) is $(M - S) \div M$.

"Wattless Current"; Power Factor Zero.—When the power factor is zero, it means that the phase difference between the current and the pressure is 90°.

The term *wattless current*, as understood, does not indicate an *absence of electrical* energy in the circuit; its elements are there,

[redacted]

but not in an available form for external work. The false power due to the so called wattless current pulsates in and out of the circuit without accomplishing any useful work.

An example of wattless current, showing that the power factor is zero is illustrated in fig. 1,353. Here the angle of lag is 90°, that is, the current is 90° behind the pressure.

The power curve is constructed from the current and pressure curves, and, as shown in the diagram, it lies as much below the zero line

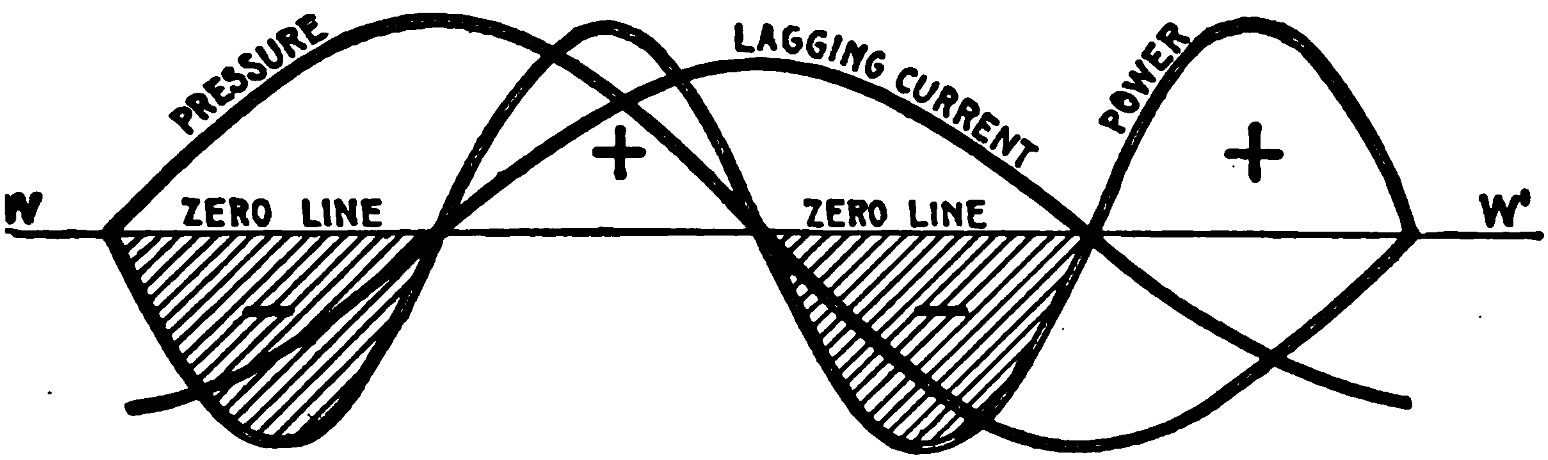


Fig. 1,353.—Example of wattless current showing that the power factor is zero when the phase difference between current and pressure is 90°. For zero power factor the current may *lead* 90° as in fig. 1,352, or *lag* 90° as here shown. Since the shaded or negative areas = the plus areas, the average power (indicated by WW′ which coincides with the zero line) is zero, that is the circuit is carrying current under pressure yet delivering no power, hence, the power factor is zero.

as above, that is, the two plus power areas which occur during each period are equal to the two negative (shaded) power areas, showing that the circuit returns as much energy as is sent out. Hence, the total work done during each period is zero, indicating that although a current be flowing, this current is not capable of doing external work.

Ques. Is the condition as just described met with in practice?

Ans. No.

Ques. Why not?

Ans. The condition just described involves that the circuit have no resistance, all the load being reactance, but it is impossible to have a *circuit without* some resistance, though the

resistance may be made very small in comparison to the reactance so that a close approach to wattless current is possible.

Ques. Give some examples where the phase difference is very nearly 90°.

Ans. If an alternator supply current to a circuit having a very small resistance and very large inductance, the current would lag nearly 90° behind the pressure. The primary current of a transformer working with its secondary on open circuit is a practical example of a current which represents very little energy.

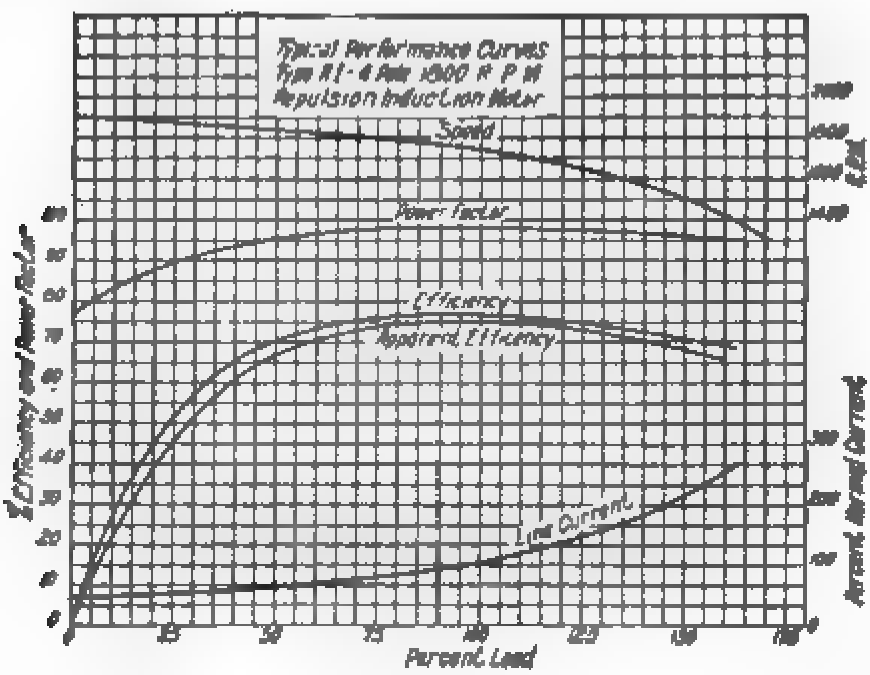


FIG. 1,354.—Performance curves of General Electric single phase repulsion induction motor.

Ques. When the phase difference between the current and pressure is 90°, why is the current called "wattless"?

Ans. Because the product of such a current multiplied by the pressure does not represent any watts *expended*.

A man lifting a weight, and then allowing it to descend the same distance to its initial position, as shown in figs. 1,355 to 1,357, presents a *mechanical* analogy of wattless current.

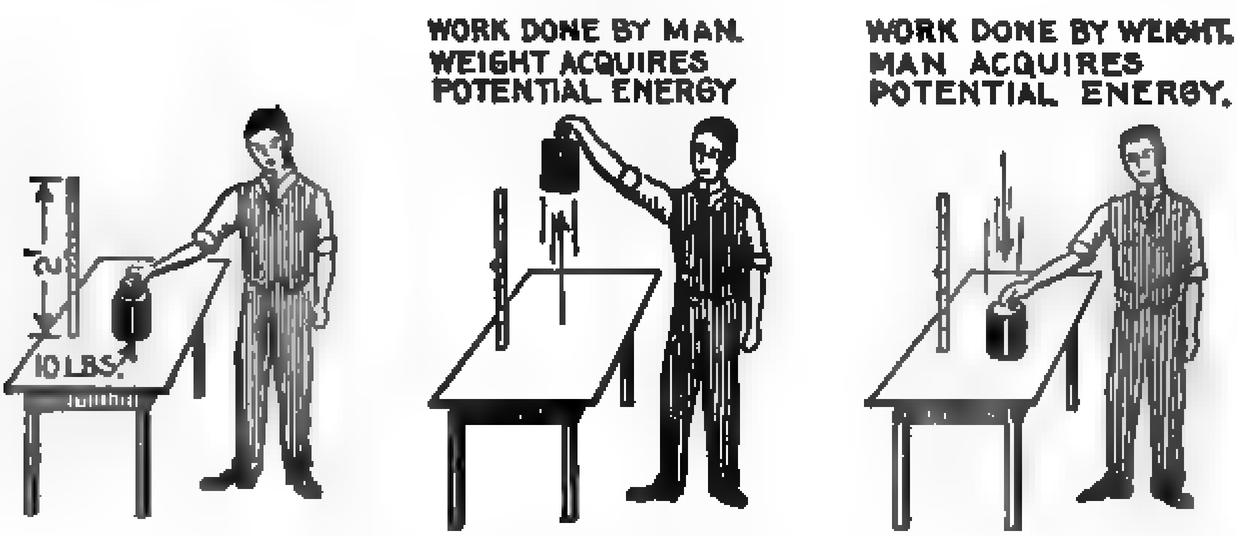
[redacted]

Let the movement of the weight represent the current and the weight the pressure. Then calling the weight 10 pounds (volts), and the distance two feet (amperes). The work done by the man (alternator) on the weight in lifting it is

10 pounds × 2 feet = 20 foot pounds..........(1)
(10 volts × 2 amperes = 20 watts.)

The work done on the man by the weight in forcing his hand down as his muscles relax is

10 pounds × 2 feet = 20 foot pounds..........(2)
(10 volts × 2 amperes = 20 watts.)



FIGS. 1,356 to 1,357.—Mechanical analogy of wattless current. If a man lift a weight any distance as from the position of fig. 1,355 to position of fig. 1,356, he does a certain amount of work on the weight giving it potential energy. When he lowers it to its original position, as in fig. 1,357, the weight loses the potential energy previously acquired, that is, it is given back to the man, the "system" (man and weight) having returned to its original condition as in fig. 1,355. During such a cycle, the work done by the man on the weight is equal to the work done by the weight on the man and no useful external work has been accomplished.

From (1) and (2) it is seen that the *work done by the man on the weight is equal to the work done by the weight on the man*, hence no useful work has been accomplished; that is, the potential energy of the weight which it originally possessed has not been increased.

Why the Power Factor is equal to Cos ϕ.—In the preceding figures showing power curves for various phase relations between current and pressure, the curves show the instantaneous values of the fluctuating power, but what is of more importance, is to determine the *average power* developed.

When the current is in phase with the pressure, it is a simple matter, because the power or

$$\textit{watts} = \textit{amperes} \times \textit{volts}$$

that is, the product of the ammeter and voltmeter readings will give the power. However, the condition of synchronism of current and pressure hardly ever exists in practice, there being more or less phase difference.

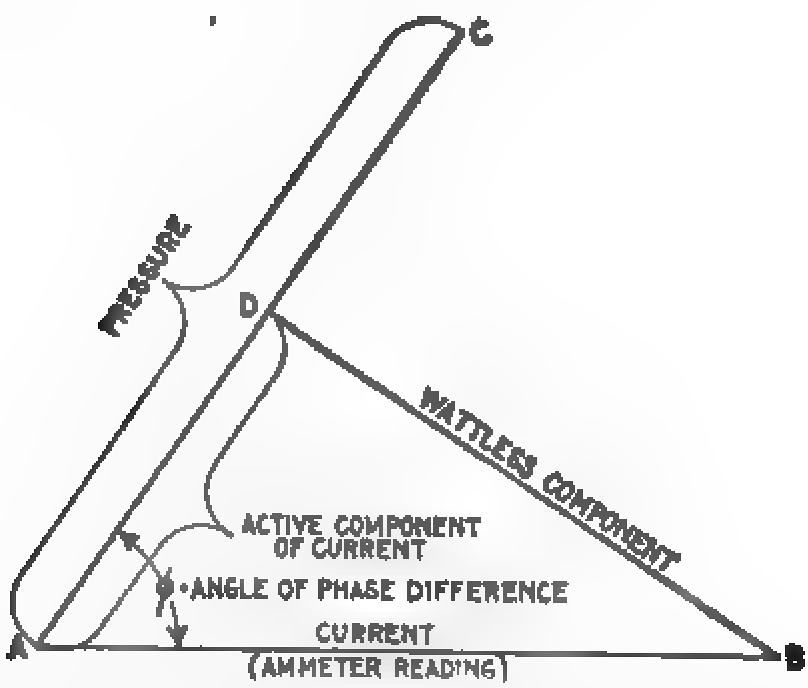


FIG. 1,358.—Method of obtaining the *active component* of the current; diagram illustrating why the power factor is equal to cos ϕ. If AB and AC be respectively the given current and pressure, or readings of the ammeter and voltmeter, and ϕ the angle of phase difference between current and pressure, then drawing from B, BD perpendicular to AC will give AD the active component. Now, true power = AC × AD, but AD = AB cos ϕ, hence true power = AC × AB cos ϕ. Again, apparent power = AC × AB, and since true power = apparent power × power factor, the power factor = cos ϕ.

When the current is not in phase with the pressure, it is considered as made up of two components at right angles to each other.

1. *The active component*, in phase with the pressure;
2. *The wattless component*, at right angles to the pressure.

With phase difference between current and pressure the *product of ammeter* and voltmeter readings do not give the true

power, and in order to obtain the latter, the *active component* of the current in phase with the pressure must be considered, that is,

$$\textit{true power} = \textit{volts} \times \textit{active amperes} \ldots\ldots\ldots\ldots (1)$$

The active component of the current is easily obtained graphically as in fig. 1,358.

With any convenient scale draw AB equal to the current as given or read on the ammeter, and AC, equal to the pressure, making the angle ϕ between AB and AC equal to the phase difference between the current and pressure.

From B, draw the line BD perpendicular to AC, then BD will be the wattless component, and AD (measured with the same scale as was used for AB) the active component of the current, or that component in phase with the pressure.

Hence from equation (1)

$$\text{true power} = \text{AC} \times \text{AD} \ldots\ldots\ldots\ldots (2)$$

Now in the right triangle ABD

$$\frac{\text{AD}}{\text{AB}} = \cos\phi$$

from which

$$\text{AD} = \text{AB}\cos\phi \ldots\ldots\ldots\ldots (3)$$

Substituting this value of AD in equation (2) gives

$$\text{true power} = \text{AC} \times \text{AB}\cos\phi \ldots\ldots\ldots (4)$$

Now the power factor may be defined as: *that quantity by which the apparent watts must be multiplied in order to give the true power.* That is

$$\textit{true power} = \textit{apparent watts} \times \textit{power factor} \ldots\ldots (5)$$

Comparing equations (4) and (5), AC × AB in (4) is equal to the apparent watts, hence, the power factor in (5) is equal to cos ϕ. That is, *the power factor is numerically equal to the cosine of the angle of phase difference between current and pressure.*

EXAMPLE I.—An alternator supplies a current of 200 amperes at a pressure of 1,000 volts. If the phase difference between the current and pressure be 30°, what is the true power developed?

In fig. 1,359, draw AB to scale, equal to 200 amperes, and draw AC of indefinite length making an angle of 30° with AB. From B, draw BD perpendicular to AC which gives AD, the active component, and which measured with the same scale as was used in laying off AB, measures 173.2 amperes. The true power developed then is

$$\text{true watts} = 173.2 \times 1{,}000 = 173.2 \text{ kw.}$$

The true power may be calculated thus:

From the table cos 30° = .866, hence

$$\text{true watts} = 200 \times 1{,}000 \times .866 = 173.2 \text{ kw.}$$

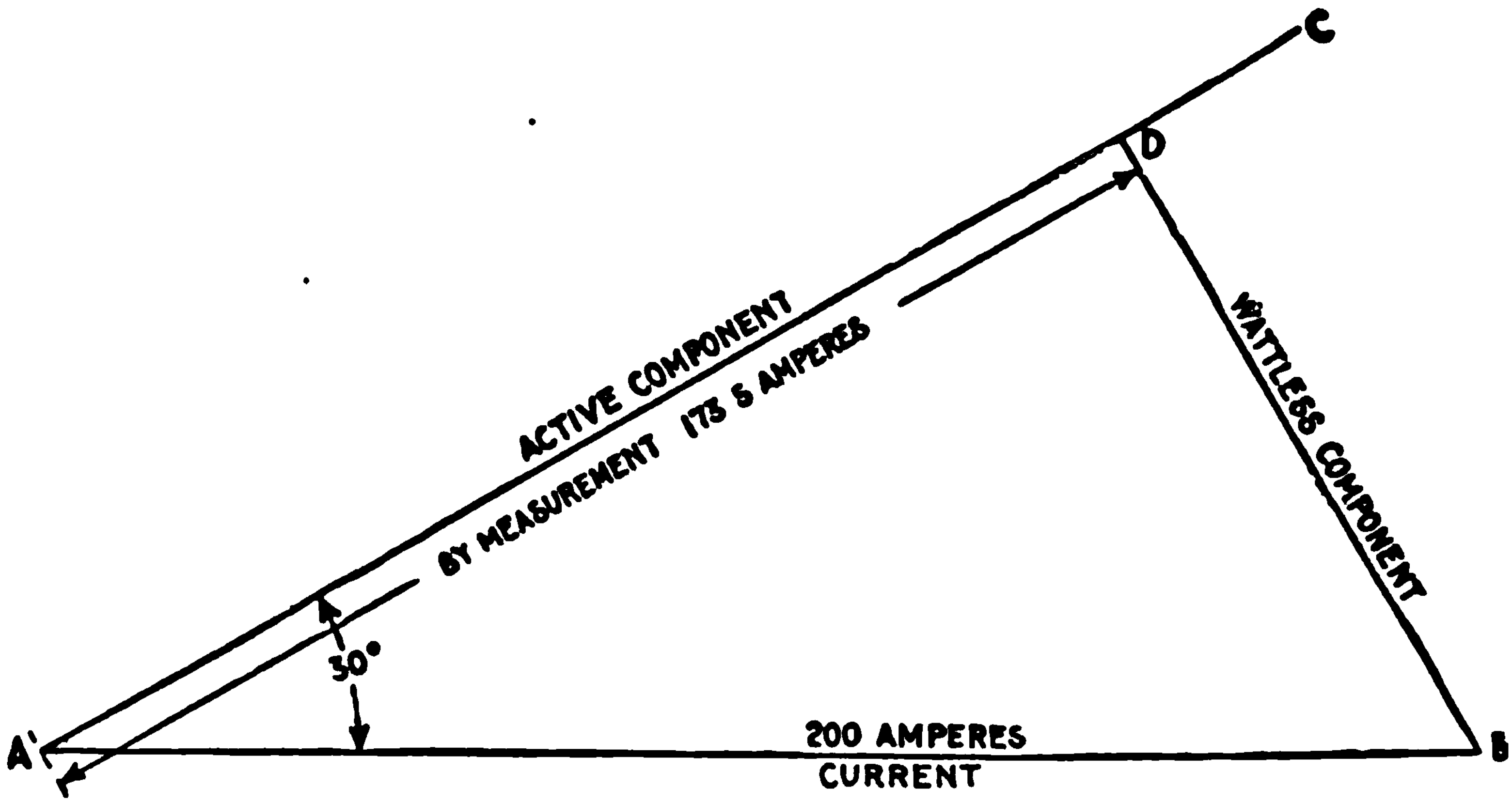


FIG. 1,359.—Diagram for obtaining the active component of the current in a circuit having a current of 200 amperes and angle of lag of 30°.

EXAMPLE II.—If in an alternating current circuit, the voltmeter and ammeter readings be 110 and 20 and the angle of lag 45°, what is the apparent power and true power?

The apparent power is simply the product of the current and pressure readings or

$$\text{apparent power} = 20 \times 110 = 2{,}200 \text{ watts}$$

The true power is the product of the apparent power multiplied by the cosine of the angle of lag. Cos 45° = .707, hence

$$\text{true power} = 2{,}200 \times .707 = 1{,}555.4 \text{ watts.}$$

[redacted]

Ques. Does the power factor apply to capacity reactance in the same way as to inductance reactance?

Ans. Yes. The angles of lag and of lead, are from the practical standpoint, treated as if they lay in the first quadrant of the circle. Even the negative sign of the tangent ϕ when it occurs is simply used to determine whether the angle be one of lag or of lead, but in finding the value of the angle from a table it is treated as a positive quantity.

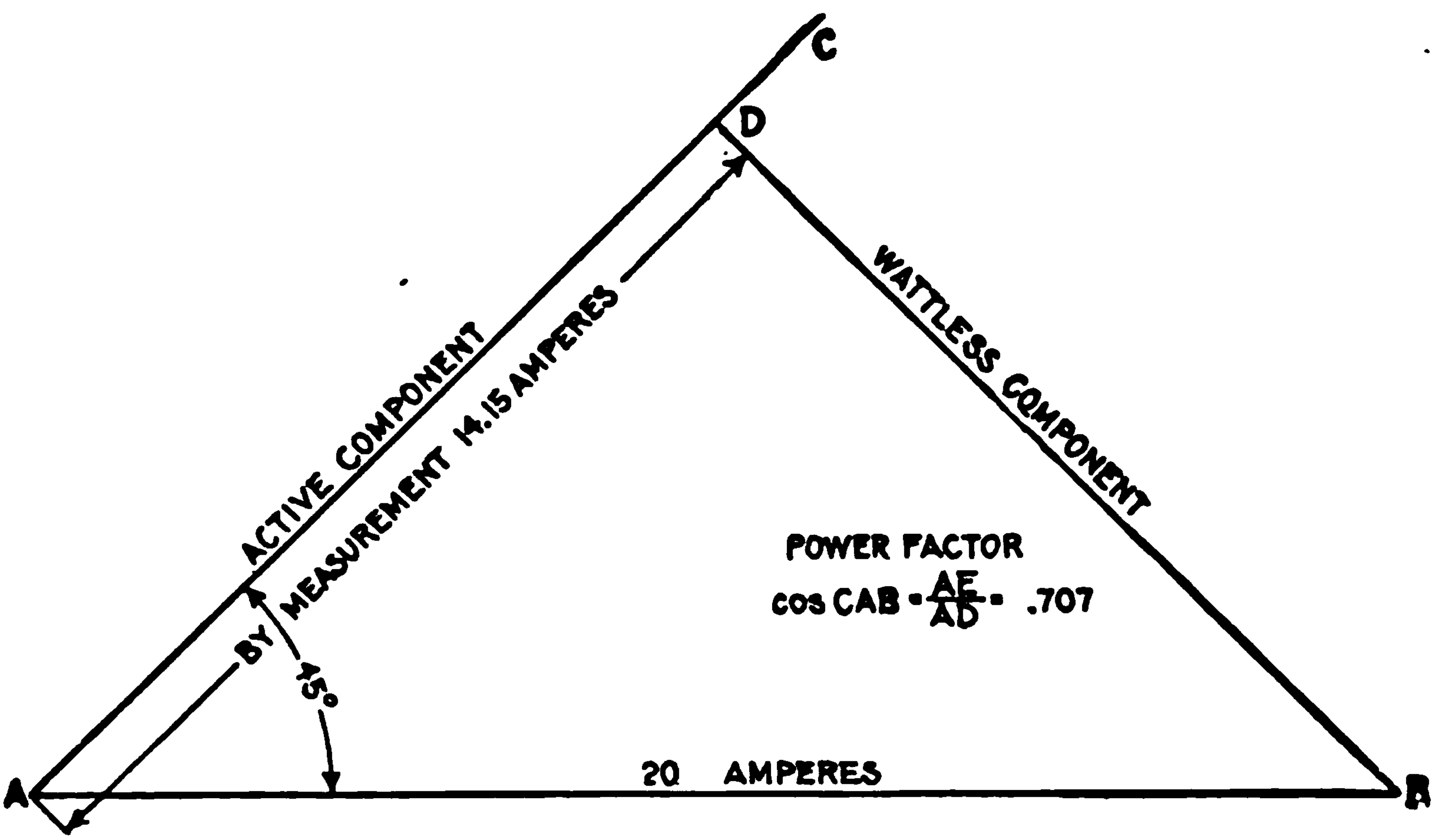


FIG. 1,360.—Diagram for obtaining the power factor for example II. With convenient scale, lay off AB = 20 amperes. From A draw AC at 45° to AB, and from B, draw BD perpendicular to AC. Then, the power factor which is equal to cosine of angle of lag, = AD + AB = (by measurement) 14.15 + 20 = .707.

Ques. In introducing capacity into a circuit to increase the power factor what should be considered?

Ans. The cost and upkeep of the added apparatus as well as the power lost in same.

Ques. How is power lost in a condenser?

Ans. The loss is principally due to a phenomenon known as *dielectric hystereses*, which is somewhat analogous to magnetic hysteresis. The rapidly alternating charges in a condenser placed in an alternating circuit may be said to cause alternating polarization of the dielectric, and consequent heating and loss of energy.

Ques. When is inductance introduced into a circuit to increase the power factor?

Ans. When the phase difference is due to an excess of capacity.

EXAMPLE.—A circuit having a resistance of 3 ohms, and a resultant reactance of 4 ohms, is connected to a 100 volt line. What is: 1, the impedance, 2, the current, 3, the apparent power, 4, the angle of lag, 5, the power factor, and 6, the true power?

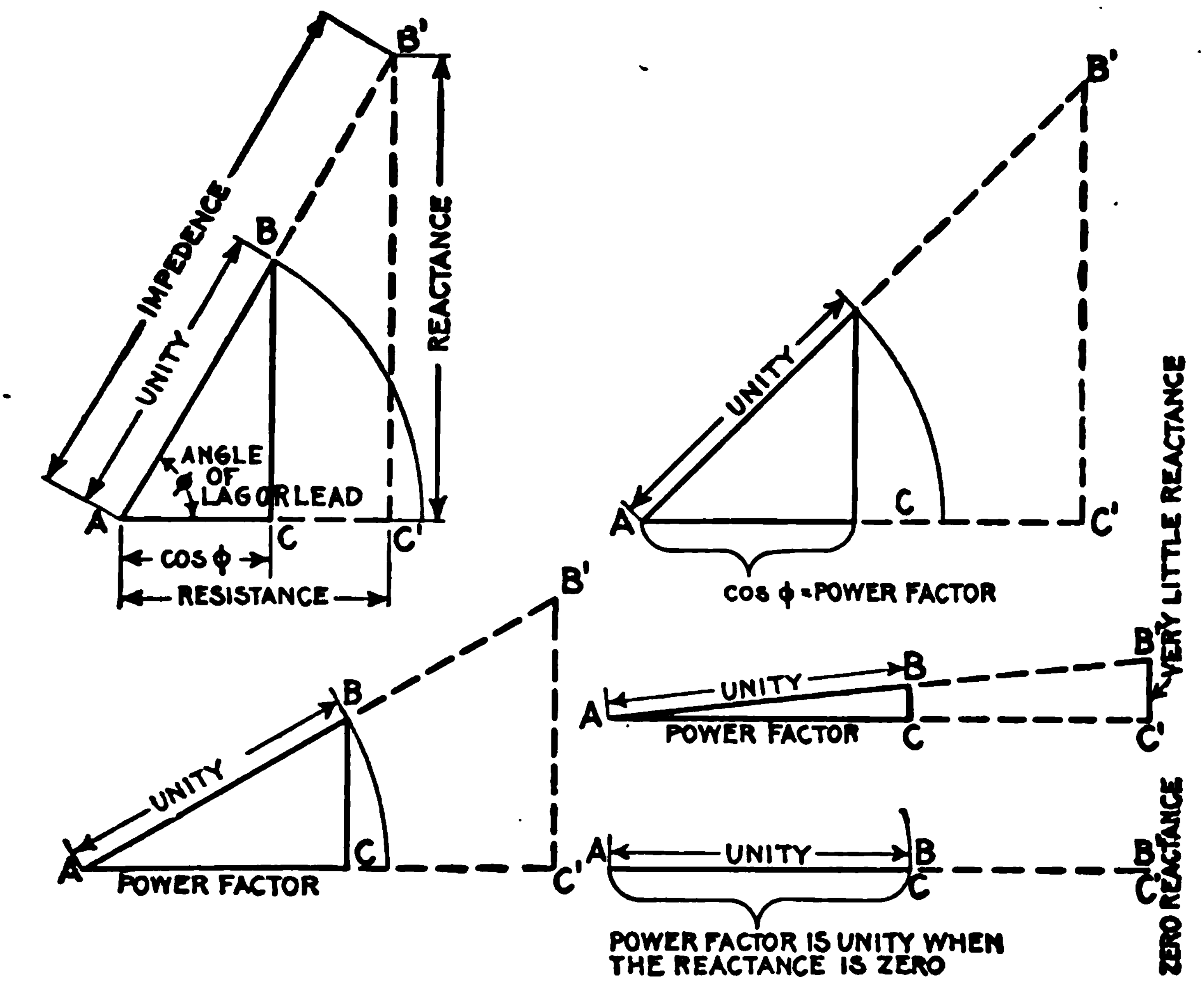
1. *The impedance of the circuit.*
   $Z = \sqrt{3^2 + 4^4} = 5$ ohms.
2. *The current.*
   current = volts + impedance = 100 + 5 = 20 amperes.
3. *The apparent power.*
   apparent power = volts × amperes = 100 × 20 = 2,000 watts.
4. *The tangent of the angle of lag.*
   $\tan\phi$ = reactance ÷ resistance = 4 + 3 = 1.33. From table of natural tangents (page 451) $\phi = 53°$.
5. *The power factor.*
   The power factor is equal to the cosine of the angle of lag, that is, power factor = cos 53° = .602 (from table).
6. *The true power.*
   The true power is equal to the apparent watts multiplied by the power factor, or

$$\text{true power} = \text{volts} \times \text{amperes} \times \cos\phi$$
$$= 100 \times 20 \times .602 = 1{,}204 \text{ watts.}$$

Ques. Prove that the power factor is unity when there is no resultant reactance in a circuit.

Ans. When there is no reactance, $\tan\phi$ which is equal to *reactance ÷ resistance* becomes $0 \div R = 0$. The angle ϕ

(the phase difference angle) whose tangent is 0 is the angle of 0 degrees. Hence, the power factor which is equal to $\cos\phi = \cos 0° = 1$.



FIGS. 1,361 to 1,365.—Diagrams illustrating why the power factor is unity or one when there is no resultant reactance in the circuit, that is, when the circuit is resonant or has only resistance. The power factor is equal to the cosine of the angle of lag (or lead). In the figures this angle is BAC or ϕ and the value of the *natural cosine* AC gives the power factor. By inspection of the figures, it is evident that decreasing the reactance decreases the angle ϕ and increases $\cos\phi$ or the power factor. The circular arc in each figure being at unity distance from the center A, the power factor with decreasing reactance evidently approaches unity as its limit, this limit being shown in fig. 1,365 where the reactance $B'C' = O$.

Ques. What is the usual value of the power factor in practice?

Ans. Slightly *less than one.*

Ques. Why is it desirable to keep the power factor near unity?

Ans. Because with a low power factor, while the alternator may be carrying its full load and operating at a moderate temperature, the consumer is paying only for the actual watts which are sent over the line to him.

For instance, if a large alternator supplying 1,000 kilowatts at 6,600 volts in a town where a number of induction motors are used on the

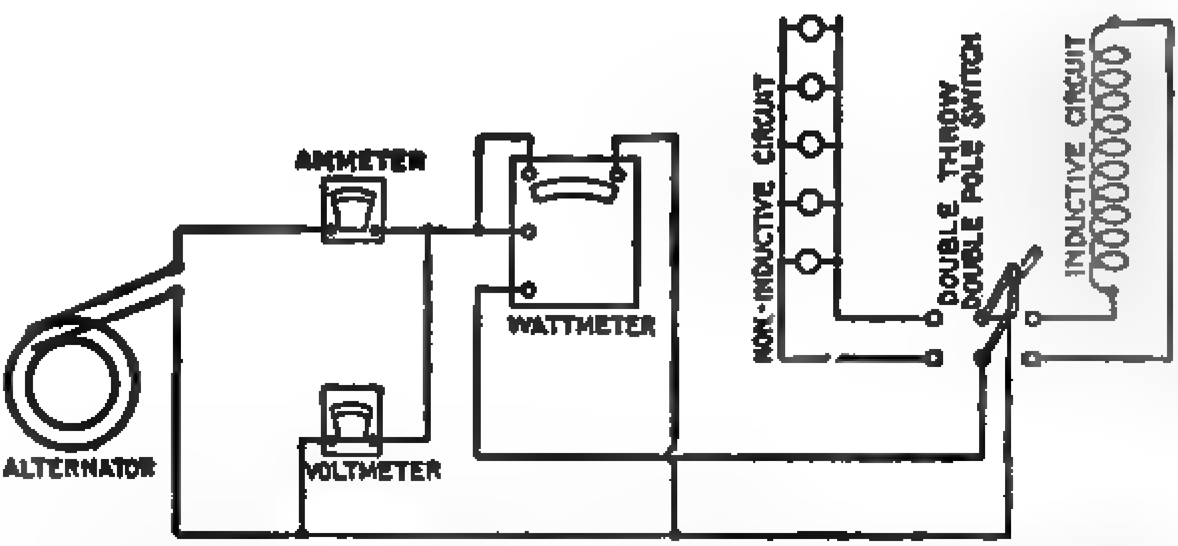


FIG. 1,266.—Diagram illustrating power factor test, when on non-inductive and inductive circuits. The instruments are connected as shown and by means of the double throw switch can be put on either the non-inductive or inductive circuit. First turn switch to left so that current passes through the lamps; for illustration, the following readings are assumed: ammeter 10, voltmeter 110, and wattmeter 1,100. The power factor then is wattmeter reading + volts × amperes = 1,100 actual watts + 1,100 apparent watts = 1, that is, on non-inductive circuit the power factor is unity. Now throwing the switch to the right connecting instruments with the inductive circuits, then for illustration the following readings may be assumed: ammeter 8, voltmeter 110, and wattmeter 684. Now, as before, power factor = wattmeter reading + volts × amperes = 684 + (8 × 110) = 684 + 880 = .78.

line be operating with a power factor of say .625 during a great portion of the time, the switchboard instruments connected to the alternator will give the following readings:

Voltmeter 6,600 volts; ammeter 242.4 amperes; power factor meter .625.

The apparent watts would equal 1,600,000 watts or 1,600 kilowatts, which, if multiplied by the power factor .625 would give 100,000,000 watts or 1,000 kilowatts which is the actual watts supplied. The alternator and line must carry 242.4 amperes instead of 151 amperes and the difference *242.4 – 151 =* 91.4 amperes represents a *wattless current* flowing in *the circuit which* causes useless heating of the alternator.

The mechanical power which is required to drive the alternator is equivalent to the actual watts produced, since that portion of the current which lags, is out of phase with the pressure and therefore requires no energy.

Ques. How are alternators rated by manufacturers in order to avoid disputes?

Ans. They usually rate their alternators as producing so many kilovolt amperes instead of kilowatts.

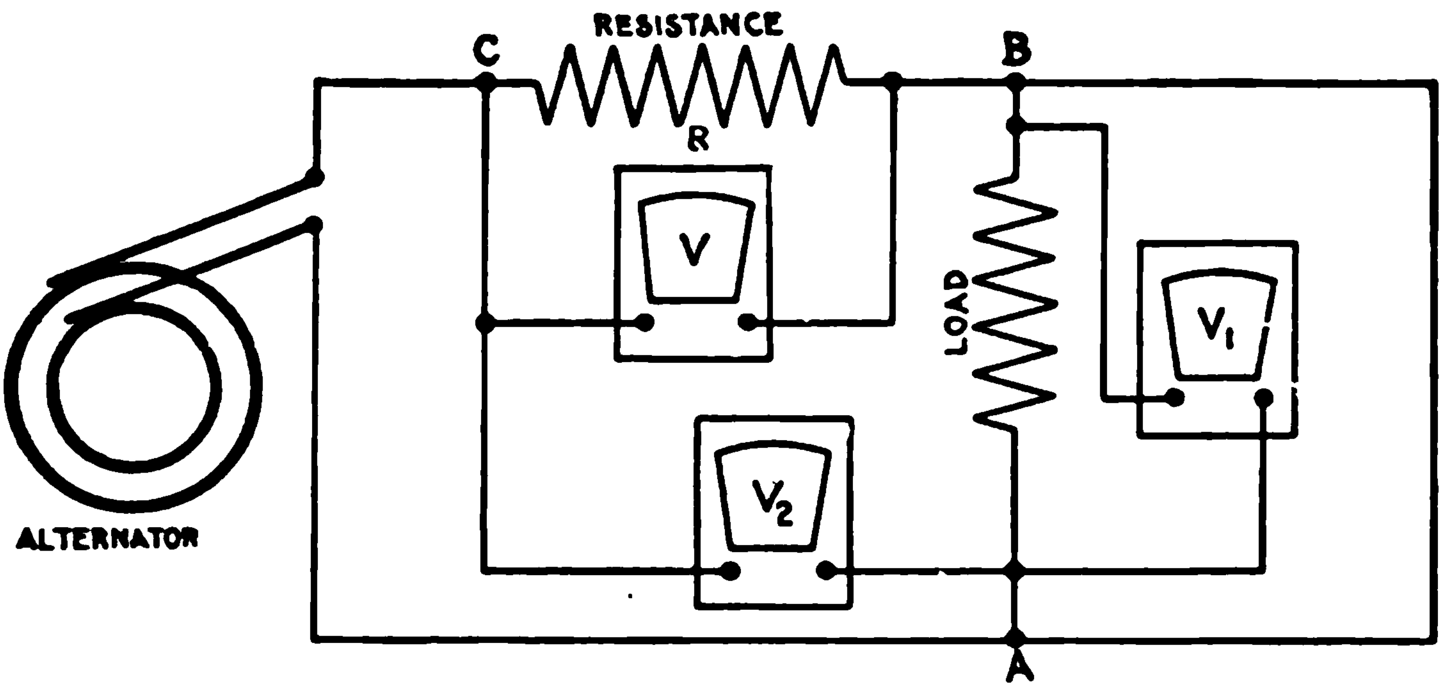


FIG. 1,367.—Ayrton and Sumpner method of alternating current power measurement. Three voltmeters are required, and accordingly the method is sometimes called the three voltmeter method. It is a good method where the voltage can be regulated to suit the load. In the figure, let the non-inductive resistance R be placed in series with the load AB. Measure the following voltages: V across the terminals of R, V_1 across the load AB, and V_2 across both, that is from A to C. Then, true watts $= (V_2^2 - V_1^2 - V^2) \div 2R$. The best conditions are when $V = V_1$, and, if $R = ½$ ohm, then $W = V_2^2 - V_1^2 - V^2$.

Ques. What is a kilovolt ampere (kva)?

Ans. A unit of apparent power in an alternating current circuit which is equal to one kilowatt when the power factor is equal to one.

The machine mentioned on page 1,120 would be designed to carry 151 amperes without overheating and also carry slight overloads for short periods. It would be rated as 6.6 kilovolts and 151 amperes which would equal approximately 1,000 kilowatts when the power factor is 1 or unity, and it should operate without undue heating. Now the *lower the power factor becomes, the greater the heating trouble will be in trying to produce the 1,000 actual kilowatts.*

[redacted]

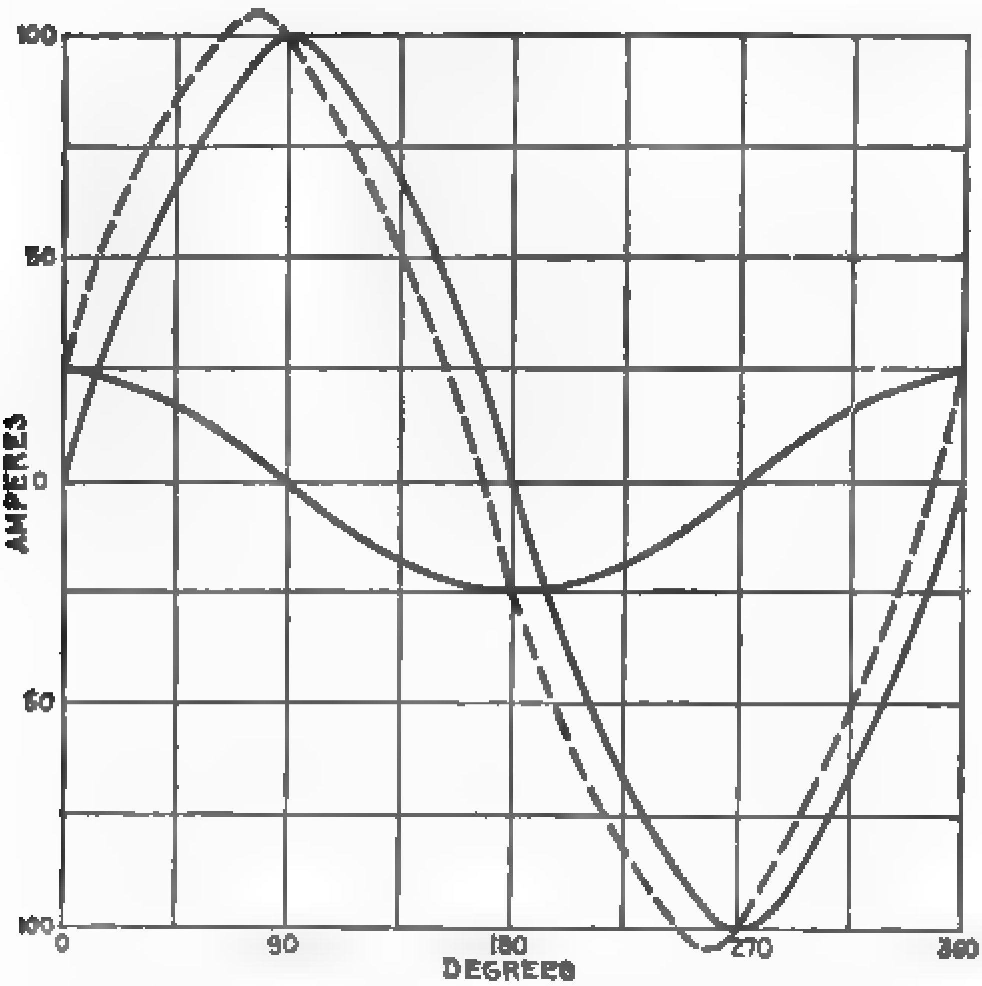


FIG. 1,368—Curves illustrating *power factor*. In a circuit having no capacity or inductance, the power is given by the product of the respective readings of the voltmeter and ammeter, as in the case of a direct current. In the case of a circuit having capacity or inductance, this product is higher than the true value as found by a wattmeter, and is known as the *apparent watts*. The ratio *true watts* ÷ *apparent watts* is known as the power factor. The current flowing in an inductive circuit, such as the primary of a transformer, is really made up of two components, as already explained, one of which (the load or active component), is in phase with the pressure, while the other the magnetizing component, is at right angles to it, that is, it attains its crest value when the other is at zero, and vice versa. To illustrate, take a complete cycle divided into 360 degrees and lay out on it the current required to correspond to a given load on the secondary of a transformer, say a crest value of 100 amperes, and at right angles to this lay out the current required for exciting the magnetic circuit of the transformer, giving A, merely for purposes of illustration, a crest value of 25 amperes. Combining these curves, the dotted curve in the figure is obtained and which represents the resultant current that would be indicated by an ammeter placed in the primary circuit of the transformer. It will be noted that this current attains its maximum at a point 14° 2′ later than the load current, giving the angle of lag. Multiplying the apparent watts by the cosine of the angle of lag gives the true watts. Now assuming the diagram to show the full load condition of the transformer, the angle of lag being 14° 2′, the power factor at full load is .97 (.97 being the value of the natural cosine of 14° 2′ as obtained from table, such as on page 451). With no external load on the transformer, the load component of the current is that necessary to make up the core losses. For instance, at 5 amperes, while the magnetizing current remains as before at 25 amperes, the angle of lag becomes 78° 41′ and the power factor .196. *It is thus seen that in transformers, induction motors, etc., the power factor is a function of the load.*

Ques. How can the power factor be kept high?

Ans. By carefully designing the motors and other apparatus and even making changes in the field current of motors which are already installed.

Ques. How is the power factor determined in station operation?

Ans. Not by calculation, but by reading a meter which forms one of the switchboard instruments.

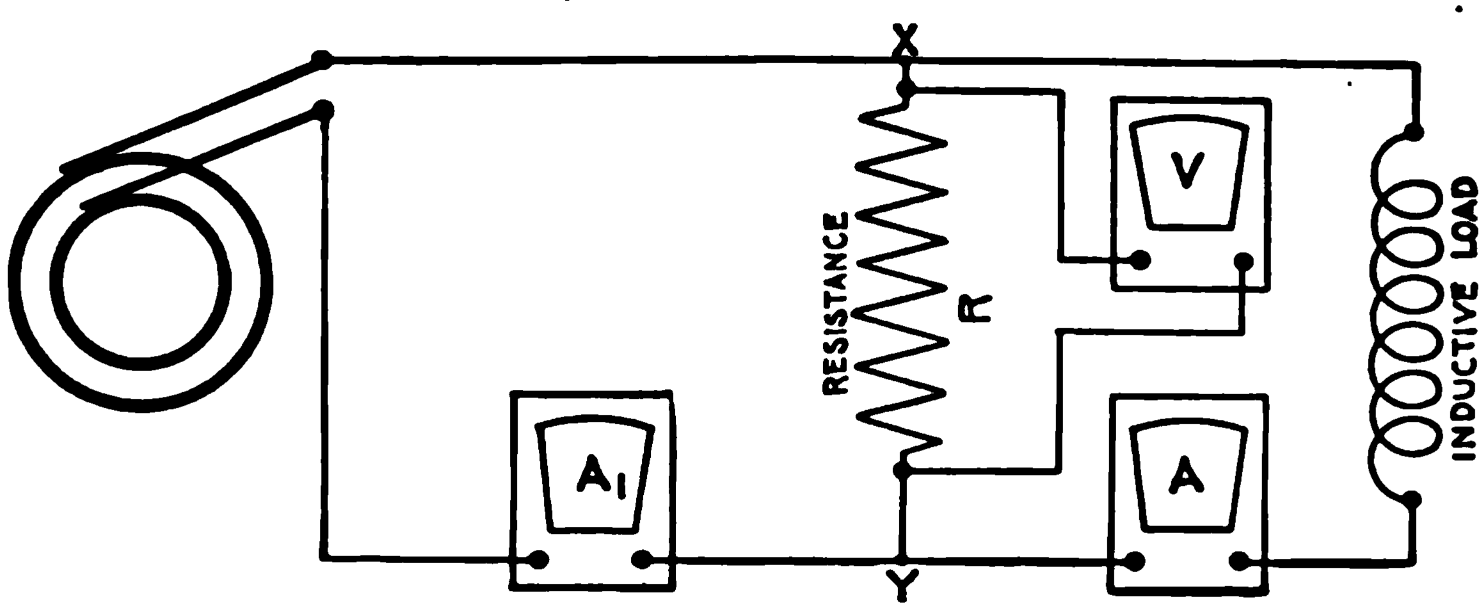


FIG. 1,368.—Fleming's combined voltmeter and ammeter method of measuring power in alternating current circuits. It is quite accurate and enables instruments in use to be checked. In the figure, R is a non-inductive resistance connected in shunt to the inductive load. The voltmeter V measures the pressure across the resistance XY. A and A_1 are ammeters connected as shown. Then, true watts = $\left(A_1^2 - A^2 - \left(\frac{V}{R}\right)^2\right) \times \frac{R}{2}$. If the volt meter V take an appreciable amount of current, it may be tested as follows: disconnect R and V at Y, and see that A and A_1 are alike; then connect R and V at Y again, and disconnect the load. A_1 will equal current taken by R and V in parallel.

Ques. When is the power factor meter of importance in station operation, and why?

Ans. When rotary converters are used on alternating current lines for supplying direct currents and the sub-station operators are kept busy adjusting the field rheostat of the rotary to maintain a high power factor and prevent overheating of the alternators during the time of day when there is the maximum demand for current or the *peak of the load.*

EXAMPLE.—An alternator delivers current at 800 volts pressure at a frequency of 60, to a circuit of which the resistance is 75 ohms and .25 henry.

Determine: *a*, the value of the current, *b*, angle of lag, *c*, apparent watts, *d*, power factor, *e*, true power.

a. Value of current

$$\text{current} = \frac{\text{pressure}}{\text{impedance}} = \frac{E}{\sqrt{R^2 + (2\pi fL)^2}}$$

$$= \frac{800}{\sqrt{75^2 + (2 \times 3.1416 \times 60 \times .25)^2}} = 6.7 \text{ amperes}$$

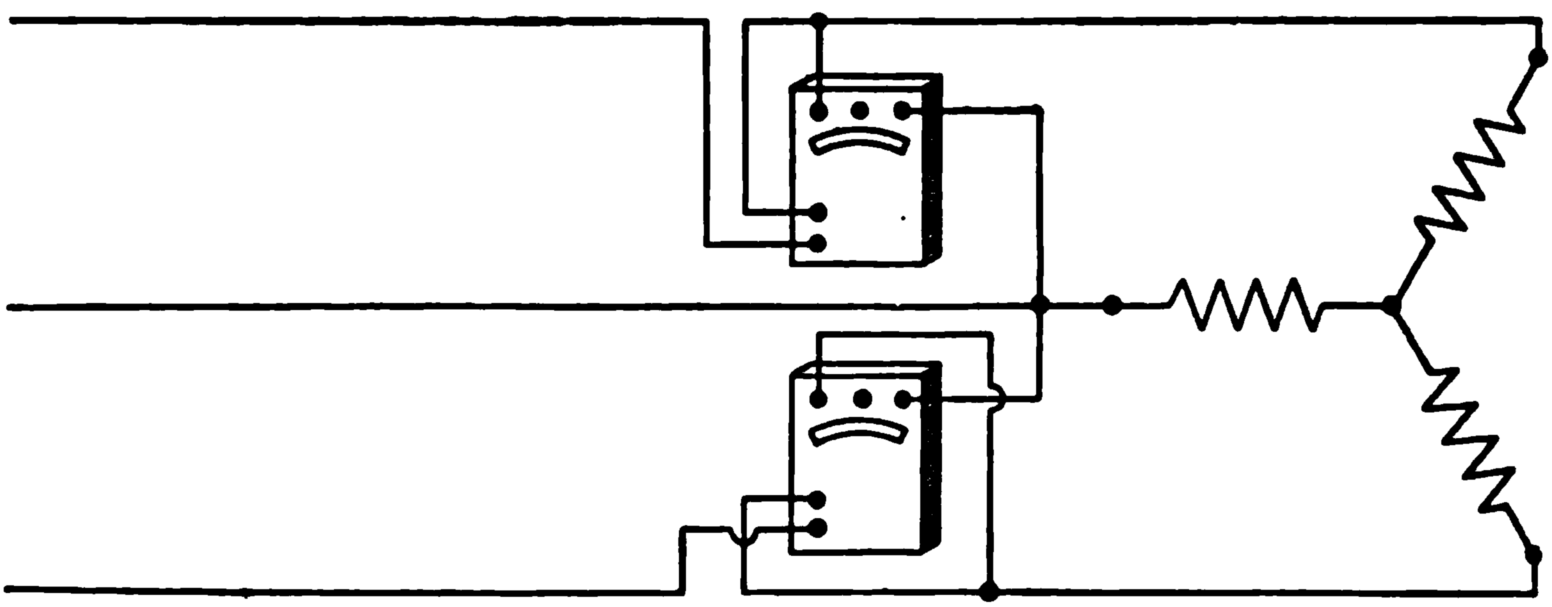


FIG. 1,369.—Wattmeter method of three phase power measurement. Two wattmeters are required in unbalanced systems as shown in the illustration. The total power transmitted is then the algebraic sum of the readings of the two wattmeters. If the power factor be greater than .5, the power is the arithmetical sum, and if it be less than .5, the power is the arithmetical difference of the readings.

b. The angle of lag

$$\tan\phi = \frac{\text{reactance}}{\text{resistance}} = \frac{2\pi fL}{R} = \frac{2 \times 3.1416 \times 60 \times .25}{75} = 1.25$$

$$\phi = \text{angle of lag} = 51° \ 15' \text{ (from table, page 451).}$$

c. The apparent power

$$\text{apparent power} = \text{volts} \times \text{amperes} = 800 \times 6.7 = 5{,}360 \text{ watts}$$
$$= 5.36 \text{ kva.}$$

d. The power factor

$$\text{power factor} = \text{cosine of the angle of lag}$$
$$= \cos 51° \ 15' = .626.$$

e. The true power

$$\text{true power} = \text{apparent power} \times \text{power factor}$$
$$= 5{,}360 \times .626 = 3{,}355 \text{ watts.}$$

CHAPTER XLIX

ALTERNATORS

Use of Alternators.—The great increase in the application of electricity for supplying power and for lighting purposes in industry, commerce, and in the home, is due chiefly to the economy of distribution of alternating current.

Direct current may be used to advantage in densely populated districts, but where the load is scattered, it requires, on account of its low voltage, too great an investment in distributing lines. In such cases the alternator is used to advantage, for while commutators can be built for collecting direct current up to 1,000 volts, alternators can be built up to 12,000 volts or more, and this voltage increased, by step up transformers of high economy, up to 75,000 or 100,000 volts. Since the copper cost is inversely as the square of the voltage, the great advantage of alternating current systems is clearly apparent.

The use of alternating current thus permits a large amount of energy to be economically distributed over a wide area from a single station, not only reducing the cost of the wiring, but securing greater economy by the use of one large station, instead of several small stations.

The higher voltages generated by alternators enables the transmission of electrical energy to vastly greater distances than possible by a direct current system, so that the energy from many waterfalls that otherwise would go to waste may be utilized.

Classes of Alternator.—There are various ways of classifying alternators. They may be divided into groups, according to: 1, the nature of the current produced; 2, type of drive; 3, method of construction; 4, field excitation; 5, service requirements, etc.

From these several points of view, alternators then may be classified:

1. With respect to the current, as:

   a. Single phase;
   b. Poly phase.

2. With respect to the type of drive, as:

   a. Belt or chain driven;
   b. Direct connected.

3. With respect to construction, as:

   a. Revolving armature;
   b. Revolving field;
   c. Inductor.
   Homopolar and heteropolar.

4. With respect to mode of field excitation, as:

   a. Self-exciting;
   b. Separately excited:
   Exciter direct connected, or gear driven.
   c. Compositely excited.

5. With respect to service requirements, as:

   a. Slow speed;
   b. Fly wheel;
   c. High speed;
   d. Water wheel type;
   e. Turbine driven.

Single Phase Alternators.—As a general rule, when alternators are employed for lighting circuits, the single phase machines are preferable, as they are simpler in construction and do not generate the unbalancing voltages often occurring in polyphase work.

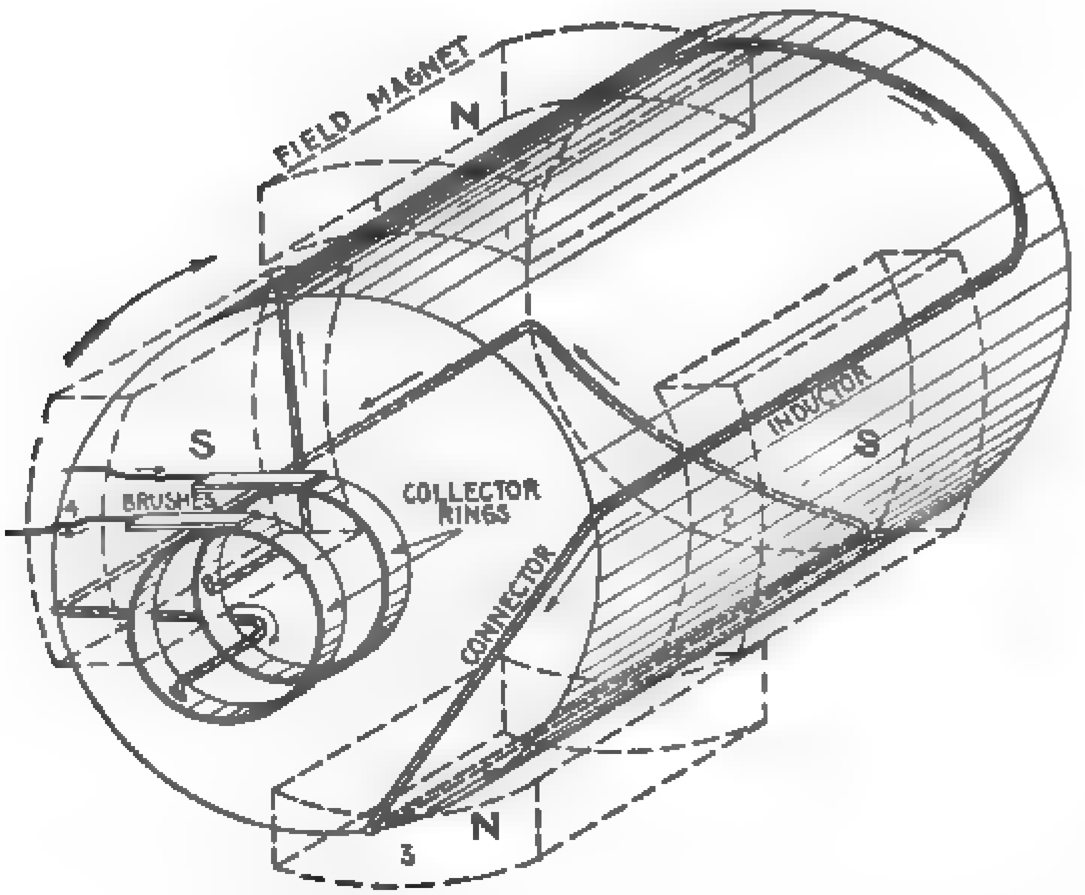


FIG. 1,370.—Elementary four-pole single phase alternator. It has four "inductors" whose pitch is the same as the pole pitch. They are connected in series and terminate at the two collector rings as shown. The poles being alternate N and S, it is evident that there will be two cycles of the current per revolution of the armature. For any number of poles then the number of cycles equals the number of poles divided by two. Applying Fleming's rule for induced currents, the direction of the current induced in the inductors is easily found as indicated by the arrows. The field magnets are excited by coils supplied with direct current, usually furnished from an external source; for simplicity this is not shown. The magnets may be considered as of the permanent type.

Ques. What are the essential features of a single phase alternator?

Ans. Fig. 1,370 shows an elementary single phase alternator. It consists of an armature, with single phase winding, field

magnets, and two collector rings and brushes through which the current generated in the armature passes to the external circuit.

Ques. In what respect do commercial machines differ mostly from the elementary alternator shown in fig. 1,370, and why?

Ans. They have a large number of poles and inductors in order to obtain the desired frequency, without excessive speed, and electro-magnets instead of permanent magnets.

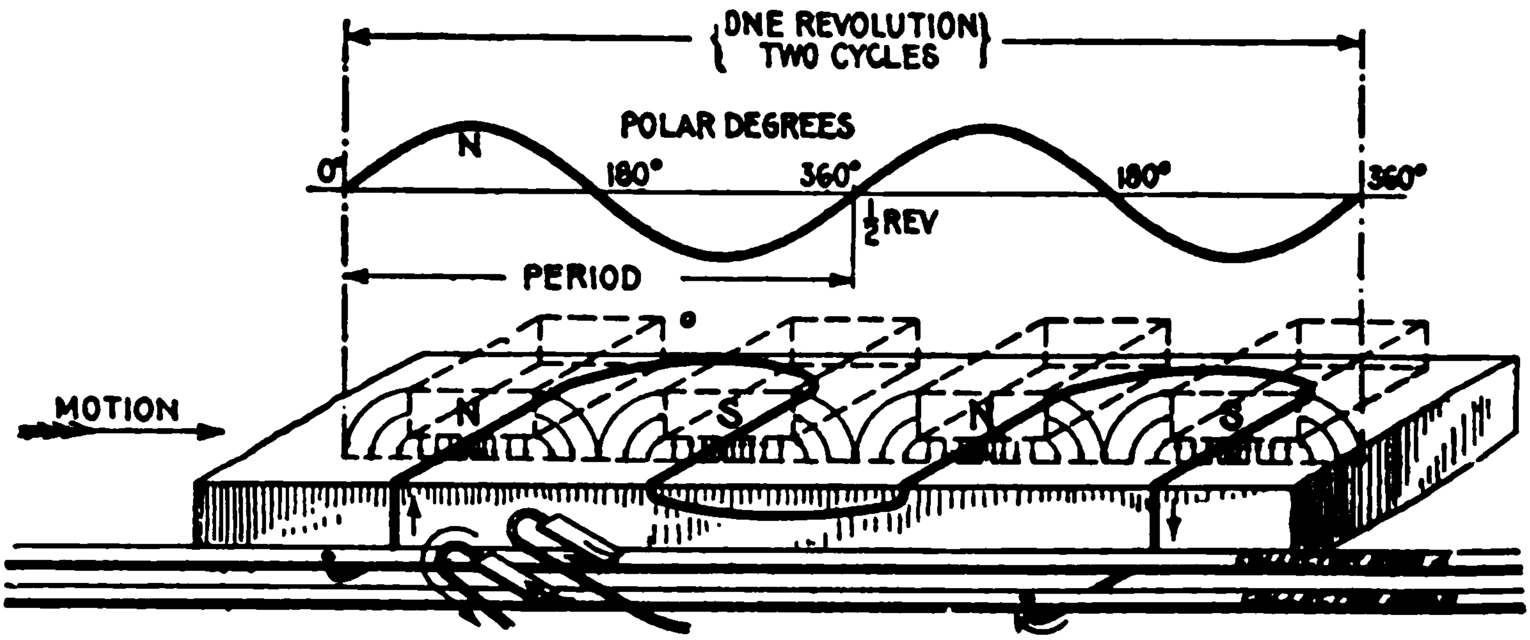


FIG. 1,371.—Developed view of elementary single phase four pole alternator and sine curve showing the alternating current or pressure generated during one revolution. The armature is here shown as a flat surface upon which a complete view of the winding is seen. If M be any position of an inductor, by projecting up to the curve gives N, the corresponding value of the current or pressure. Magnetic lines are shown at the poles representing a field decreasing in intensity from a maximum at the center to zero at points half way between the poles, this being the field condition corresponding to the sine form of wave. In actual machines the variation from the sine curve is considerable in some alternators. See figs. 1,247 and 1,248.

Ques. In actual machines, why must the magnet cores be spaced out around the armature with considerable distance between them?

Ans. In order to get the necessary field winding on the cores, and also to prevent undue magnetic leakage taking place, laterally from one limb to the next of opposite sign.

[redacted]

Ques. Is there any gain in making the width of the armature coils any greater than the pole pitch, and why?

Ans. No, because any additional width will not produce more voltage, but on the contrary will increase the resistance and inductance of the armature.

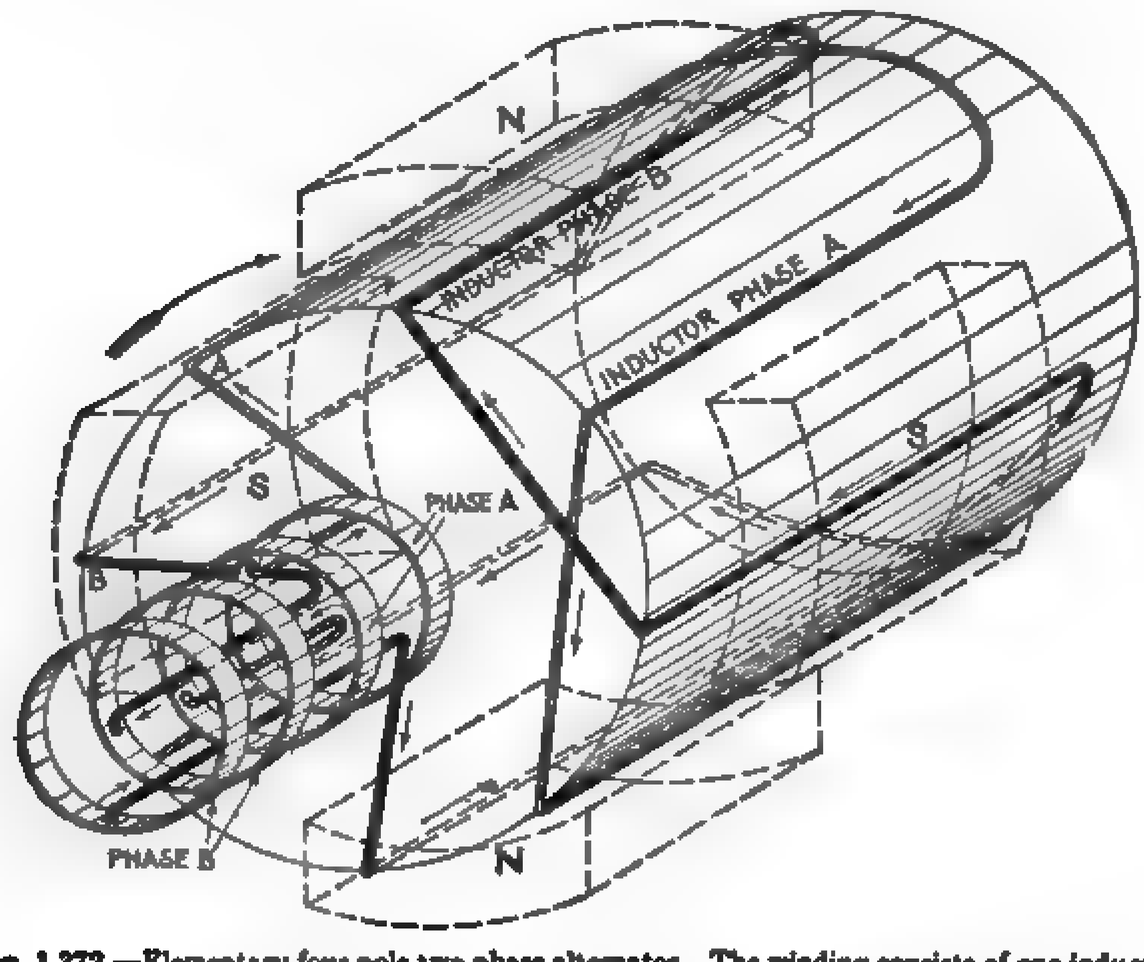


FIG. 1,272.—Elementary four pole two phase alternator. The winding consists of one inductor per phase per pole, that is, four inductors per phase, the inductors of each phase being connected in series by the "connectors" and terminating at the collector rings. This arrangement requires four collector rings, giving two independent circuits. The pitch of the inductors of each phase is equal to the pole pitch, and the phase difference is equal to one-half the pole pitch, that is, phase B winding begins at B, a point half-way between inductors A and A′ of phase A winding. Hence when the current or pressure in phase A is at a maximum, in the ideal case, when inductor A for instance is under the center of a pole, the current or pressure in B is zero, because B is then half-way between the poles.

Polyphase Alternators.—A multiphase or polyphase alternator is one which delivers two or more alternating currents differing in phase by a definite amount.

For example, if two armatures of the same number of turns each be connected to a shaft at 90 degrees from each other and revolved in a bipolar field, and each terminal be connected to a collector ring, two separate alternating currents, differing in phase by 90 degrees, will be delivered to the external circuit. Thus a two phase alternator will deliver two currents differing in phase by one-quarter of a cycle, and similarly a three phase alternator (the three armatures of which are set 120 degrees from each other) will deliver three currents differing in phase by one-third of a cycle.

In practice, instead of separate armatures for each phase, the several windings are all placed on one armature and in such sequence that the

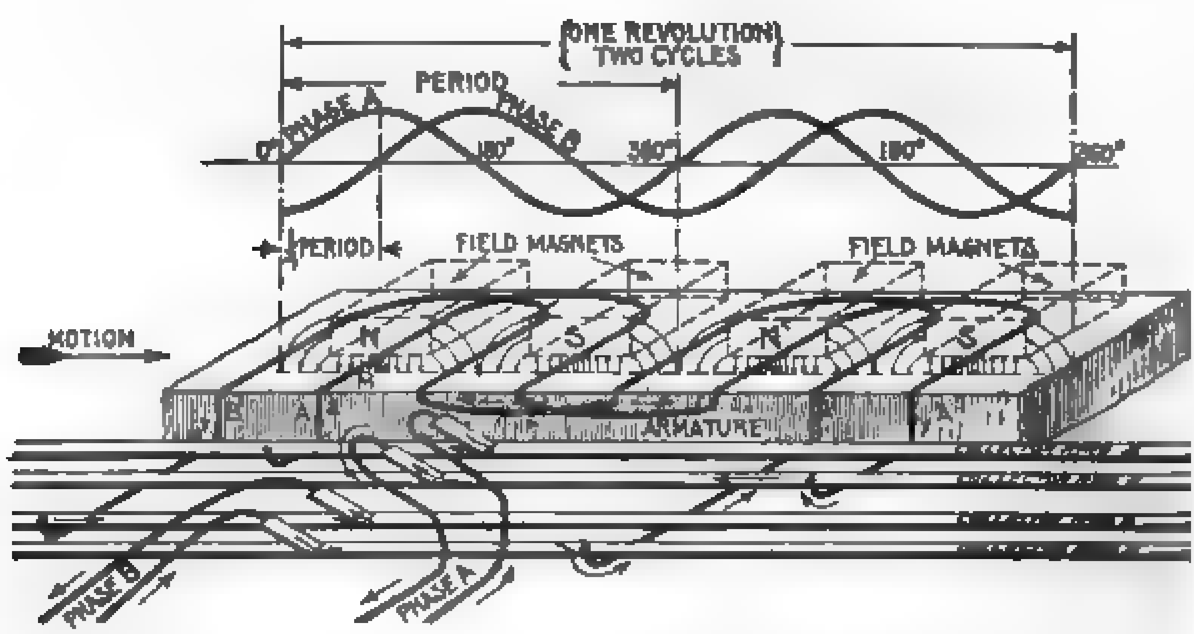


FIG. 1,373—Developed view of elementary two phase four pole alternator and sine curves showing the alternating current or pressure generated during one revolution of the armature. The complete winding for the three phases are here visible, the field magnets being represented as transparent so that all of the inductors may be seen. By applying Fleming's rule, as the inductors progress under the poles, the directions and reversals of current are easily determined, as indicated by the sine curves. It will be seen from the curves that four poles give two cycles per revolution. Inductors A, and B are lettered to correspond with fig. 1,372, with which they should be compared.

currents are generated with the desired phase difference between them as shown in the elementary diagrams 1,372 and 1,373 for two phase current, and figs. 1,374 and 1,375 for three phase current.

Ques. What use is made of two and three phase current?

Ans. They are employed rather for power purposes than for *lighting, but such* systems are often installed for both services

Ques. How are they employed in each case?

Ans. For lighting purposes the phases are isolated in separate circuits, that is, each is used as a single phase current. For driving motors the circuits are combined.

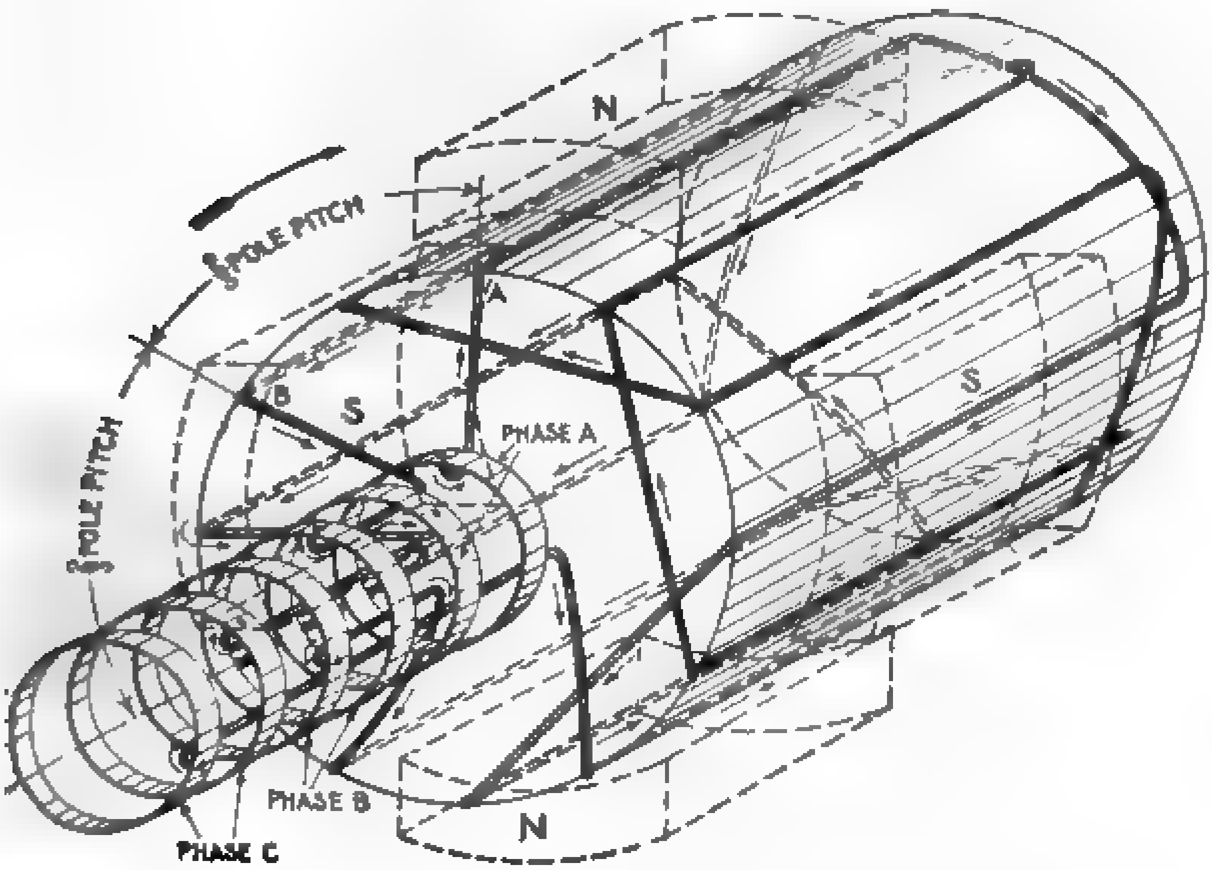


FIG. 1,374.—Elementary four pole three phase alternator. There are three sets of inductors, each set connected in series and spaced on the drum with respect to each other two-thirds pole pitch apart. As shown, six collector rings are used, but on actual three phase machines only three rings are employed, as previously explained. The inductors have distinctive coverings for the different phases. The arrows indicate the direction in which the induced pressures tend to cause currents.

Ques. Why are they combined for power purposes?

Ans. On account of the difficulty encountered in starting a motor with single phase current.

Ferarris, of Italy, *in 1888 discovered* the important principle of the *production of a rotating magnetic* field by means of two or more

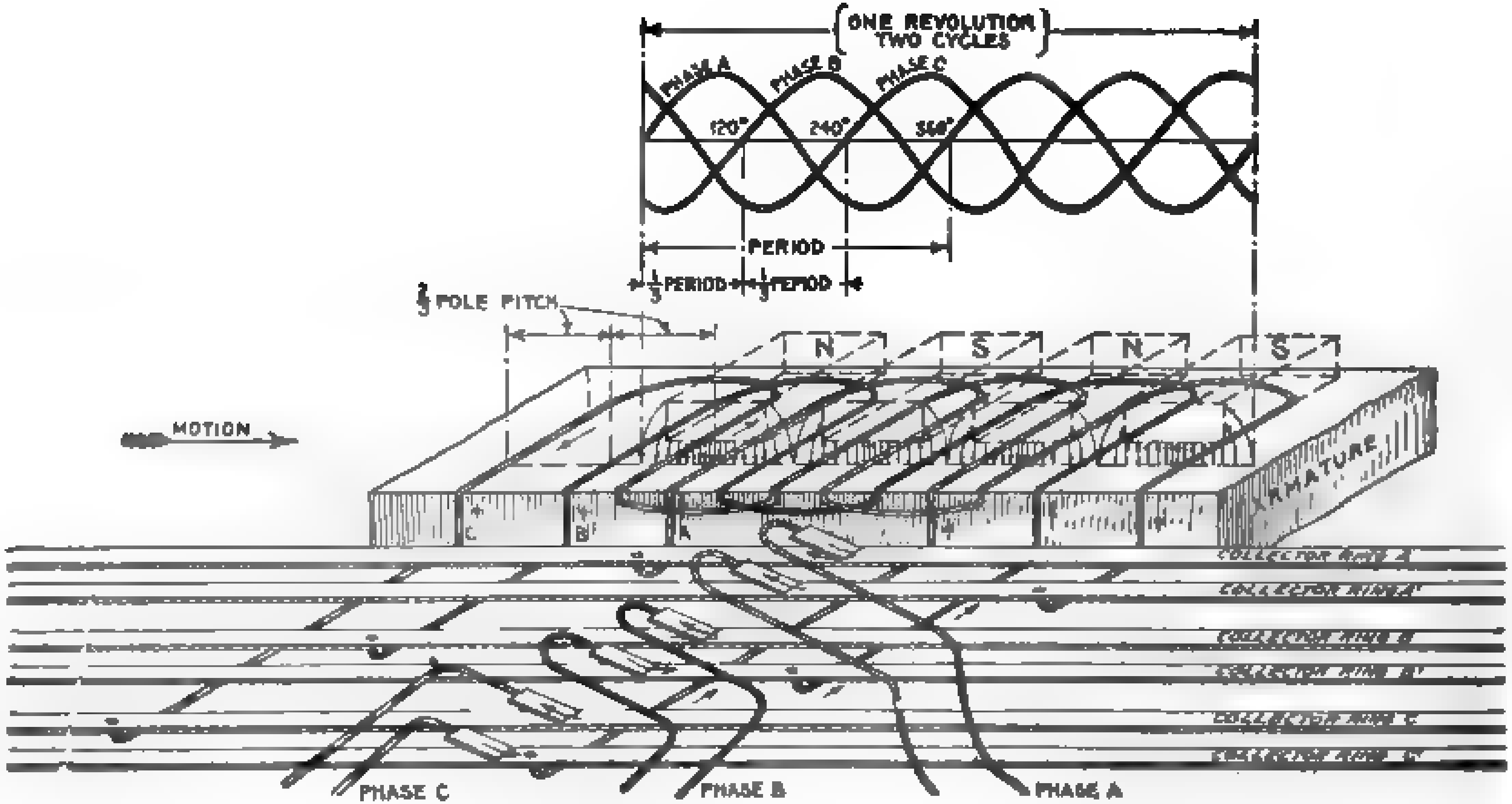


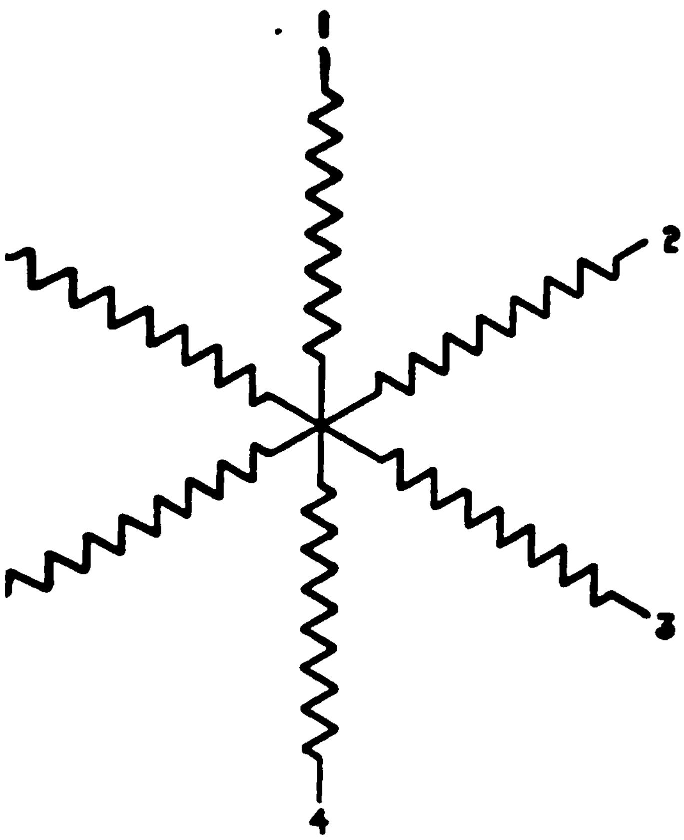
FIG. 1,375.—Elementary four-pole three-phase alternator and sine curves showing current or pressure conditions for one revolution. Six collector rings are shown giving three independent circuits. The pitch of the inductors for each phase is the same as the pole pitch, and the phase difference is equal to two-thirds of the pole pitch, giving the sequence of current or pressure waves as indicated by the sine curves. The waves follow each other at ⅓ period, that is, the phase difference is 120 degrees. Inductors A, B, and C, the beginning of each phase winding, are lettered to correspond with fig. 1,374, with which they should be compared.

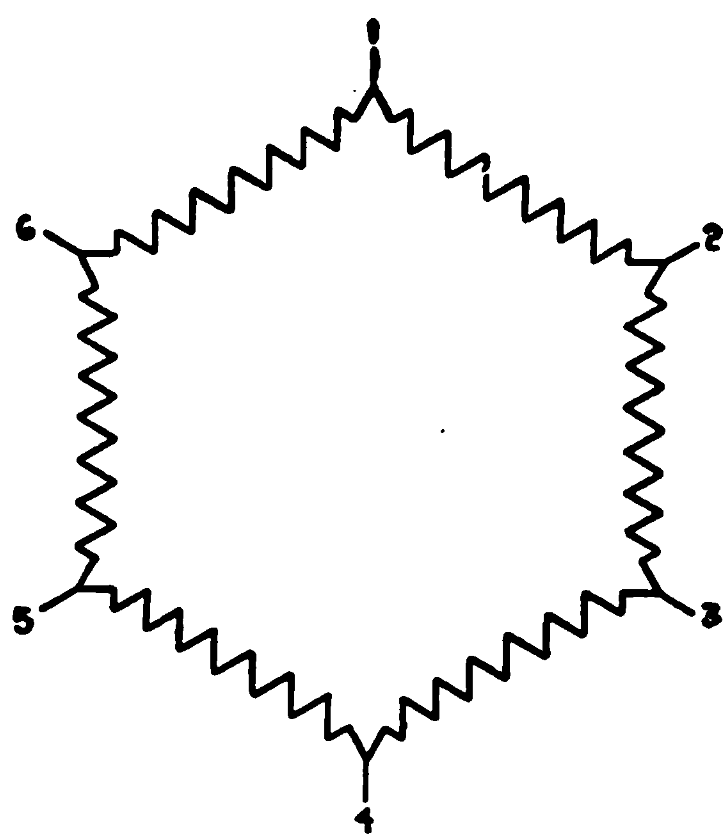
[redacted]

alternating currents displaced in phase from one another, and he thus made possible by means of the induction motor, the use of polyphase currents for power purposes.

Ques. What is the difficulty encountered in starting a otor with single phase current?

Ans. A single phase current requires either a synchronous ɔtor to develop mechanical power from it, or a specially con- ucted motor of dual type, the idea of which is to provide a





. 1,376.—Diagram of six phase winding with star grouping, being equivalent to a three phase winding in which the three phases are disconnected from each other and their middle points united at a common junction.

. 1,377.—Diagram of six phase winding with mesh grouping.

ethod of getting rotation by foreign means and then to throw the single phase current for power.

Six Phase and Twelve Phase Windings.—These are quired for the operation of rotary converters. The phase fference in a six phase winding is 60 degrees and in a twelve

phase winding 30 degrees. A six phase winding can be made out of a three phase winding by disconnecting the three phases from each other, uniting their middle points at a common junction, as shown by diagram fig. 1,376. This will give a star grouping with six terminals.

In the case of a mesh grouping, each of the three phases must be cut into two parts and then reconnected as shown in fig. 1,377.

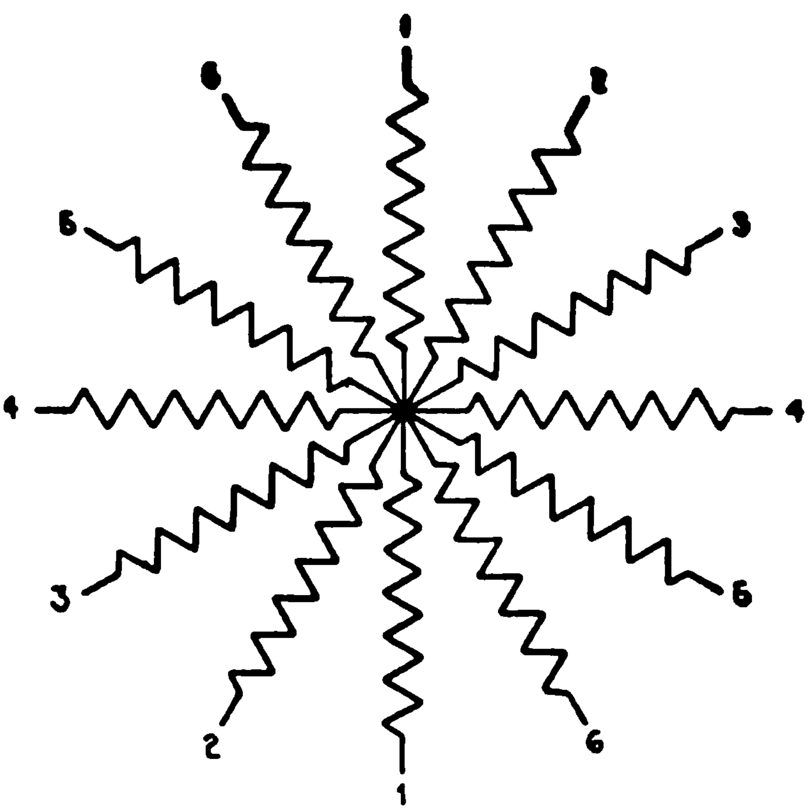


FIG. 1,378.—Diagram of twelve phase winding star grouping.

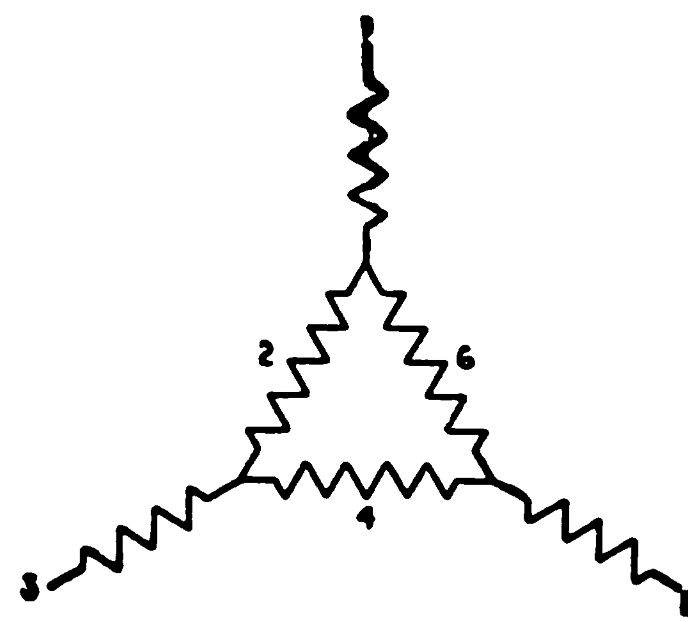


FIG. 1,379.—Diagram of six phase winding consisting of combination of mesh and star grouping.

As the phase difference of a twelve phase winding is one-half that of a six phase winding, the twelve phases may be regarded as a star grouping of six pairs crossed at the middle point of each pair as shown in fig. 1,378, or in mesh grouping for converters they may be arranged as a twelve pointed polygon. They may also be grouped as a combination of mesh and star as shown in *fig. 1,379, which,* however, is not of general interest.

[redacted]

Belt or Chain Driven Alternators.—The mode in which power is transmitted to an alternator for the generation of current is governed chiefly by conditions met with where the machine is to be installed.

In many small power stations and isolated plants the use of a belt drive is unavoidable. In some cases the prime mover is already installed and cannot be conveniently arranged for

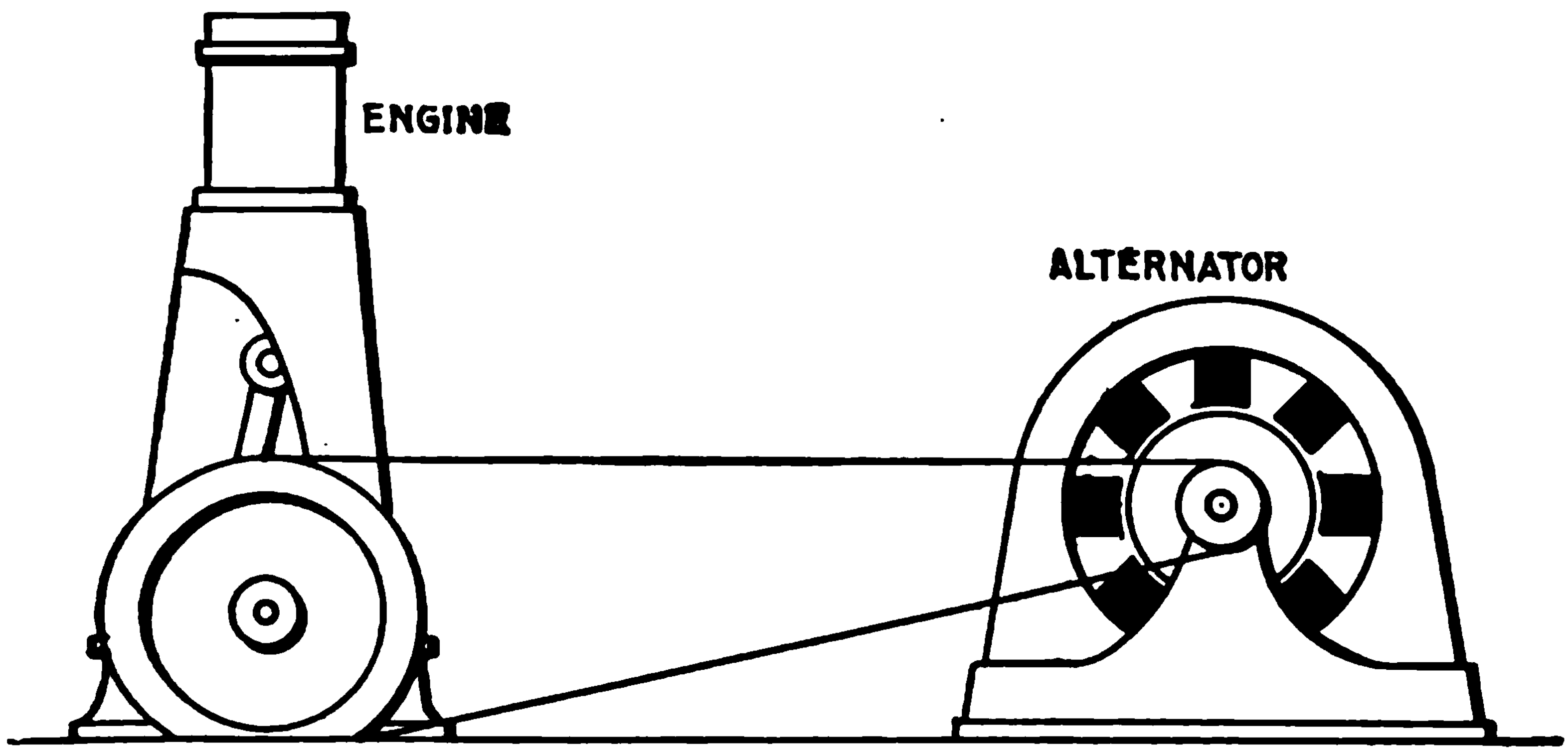


FIG. 1,380.—Belt-driven alternator. By use of a belt, any desired speed ratio is obtained, enabling the use of a high speed alternator which, being smaller than one of slow speed, is cheaper. It affords means of drive for line shaft and has other advantages, but requires considerable space and is not a "positive" drive. Belting exerts a side pull which results in friction and wear of bearings. Means for tightening the belt as shown in fig. 1,381, or equivalent, must be provided.

direct connection, in others the advantage to be gained by an increase in speed more than compensates for the loss involved in belt transmission.

There are many places where belted machines may be used advantageously and economically. They are easily connected to an existing source of power, as, for instance, a line shaft used for driving other machinery, and for comparatively small installations they are lower in first cost than direct connected

machines. Moreover, when connected to line shaft they are run by the main engine which as a rule is more efficient than a small engine direct connected.

Where there is sufficient room between pulley centers, a belt is a satisfactory medium for power transmission, and one that is largely used. It is important that there be liberal distance between centers, especially in the case of generators or motors belted to a medium or slow speed engine, because, owing to the high speed of rotation of the electric machines, there is

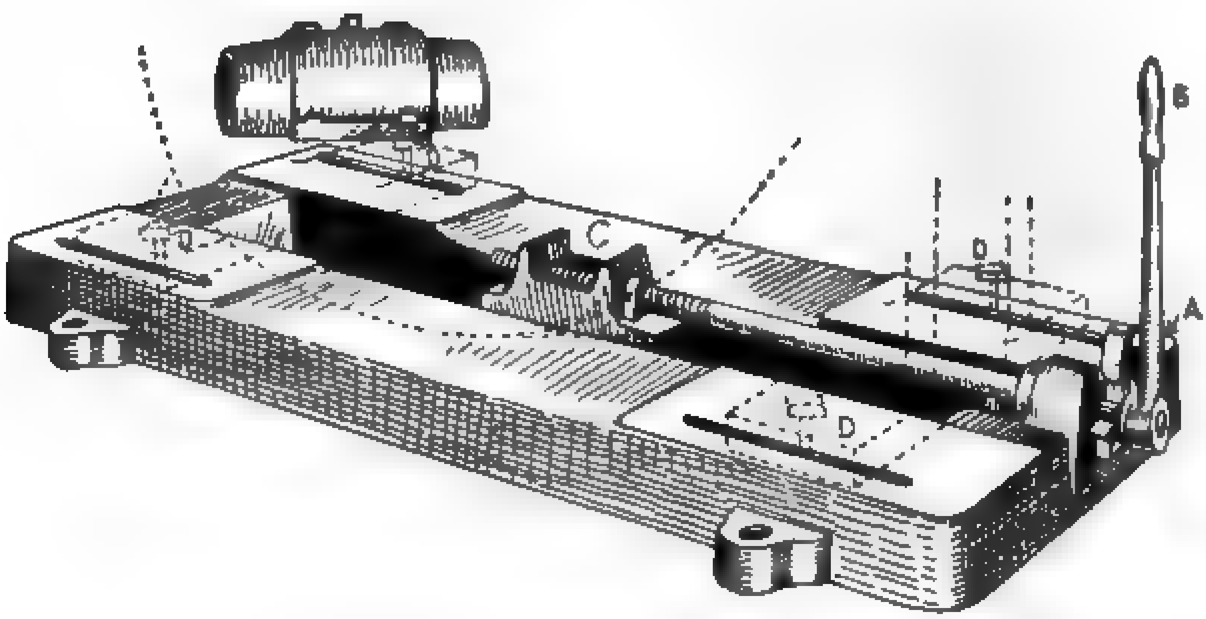


FIG. 1,381.—Sub-base and ratchet device for moving alternator to tighten belt. A ratchet A, operated by lever B, works the block C by screw connection, causing it to move the block. The latter, engaging with the frame, causes it to move, thus providing adjustment for belt. After tightening belt, the bolts D, which pass through the slots in the sub-base, are tightened, thus securing the machine firmly in position.

considerable difference in their pulley diameters and the drive pulley diameter; hence, if they were close together, the arc of contact of the belt with the smaller pulley would be appreciably reduced, thus diminishing the tractive power of the belt.

Ques. What provision should be made in the design of an alternator to adapt it to belt drive?

Ans. Provision should be made for tightening the belt.

FIG. 1,388.—Allis-Chalmers pedestal type, belted alternator. The bearings are of the ring oiling form with large oil reservoirs. The bearings have spherical seats and are self aligning.

Ques. How is this done?

Ans. Sometimes by an idler pulley, but usually by mounting the machine on a sub-base provided with slide rails, as in fig. 1,381, the belt being tightened by use of a ratchet screw which moves the machine along the base.

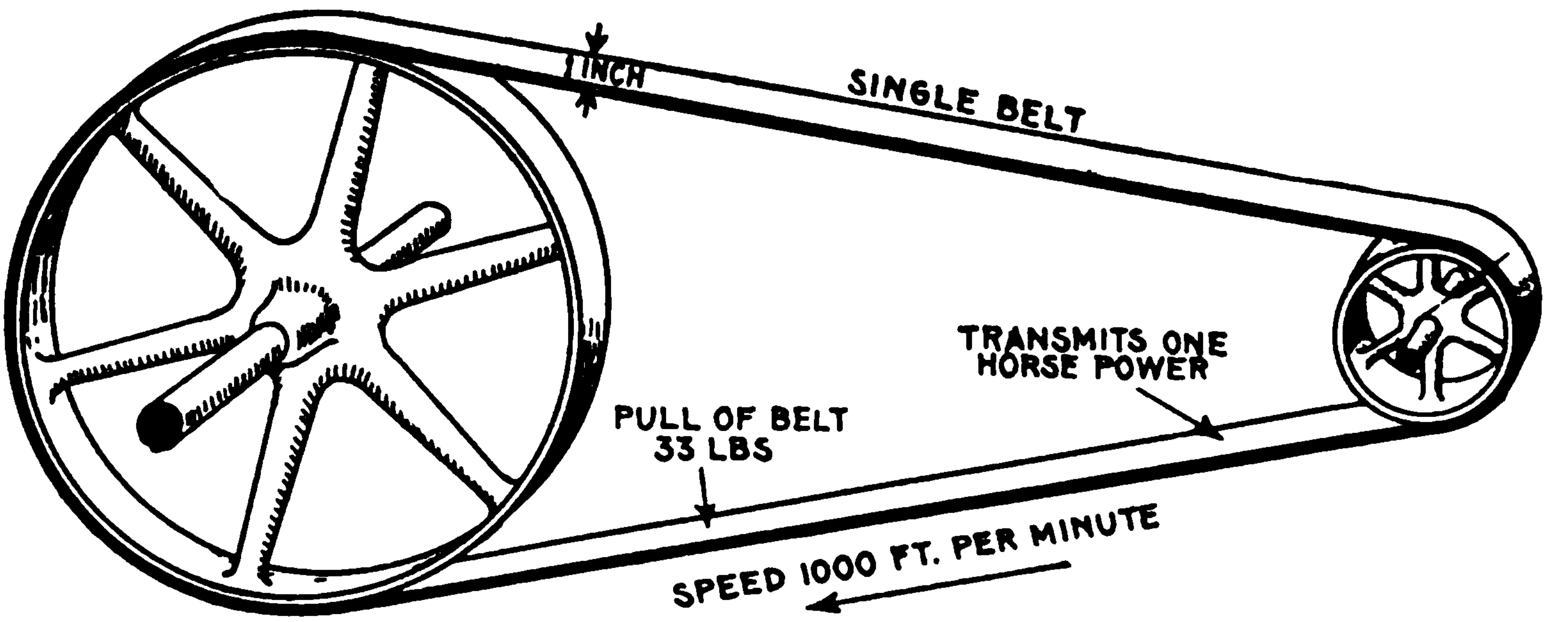


FIG. 1,383.—Diagram illustrating rule for horse power transmitted by belts. *A single belt travelling at a speed of 1,000 feet per minute will transmit one horse power; a double belt will transmit twice that amount*, assuming that the thickness of a double belt is twice that of a single belt. This is conservative practice, and a belt so proportioned will do the work in practically all cases. The above rule corresponds to a pull of 33 lbs. per inch of width. Many designers proportion single belts for a pull of 45 lbs. For double belts of average thickness, some writers say that the transmitting efficiency is to that of single belts as 10 is to 7. This should not be applied to the above rule for single belts, as it will give an unnecessarily large belt.

Ques. Give a rule for obtaining the proper size of belt to deliver a given horse power.

Ans. *A single belt travelling at a speed of one thousand feet per minute will transmit one horse power; a double belt will transmit twice that amount.*

This corresponds to a working strain of 33 lbs. per inch of width for single belt, or 66 lbs. for double belt.

Many writers give as safe practice for single belts in good condition *a working tension* of 45 lbs. per inch of width.

Ques. What is the best speed for maximum belt economy?

Ans. From 4,000 to 4,500 feet per minute.

EXAMPLE.—What is the proper size of double belt for an alternator having a 16 inch pulley, and which requires 50 horse power to drive it at 1,000 revolutions per minute full load?

The velocity of the belt is

circumference in feet × revolutions = feet per minute

$$\frac{16}{12} \times 3.1416 \quad \times \quad 1{,}000 \quad = \quad 4{,}188.$$

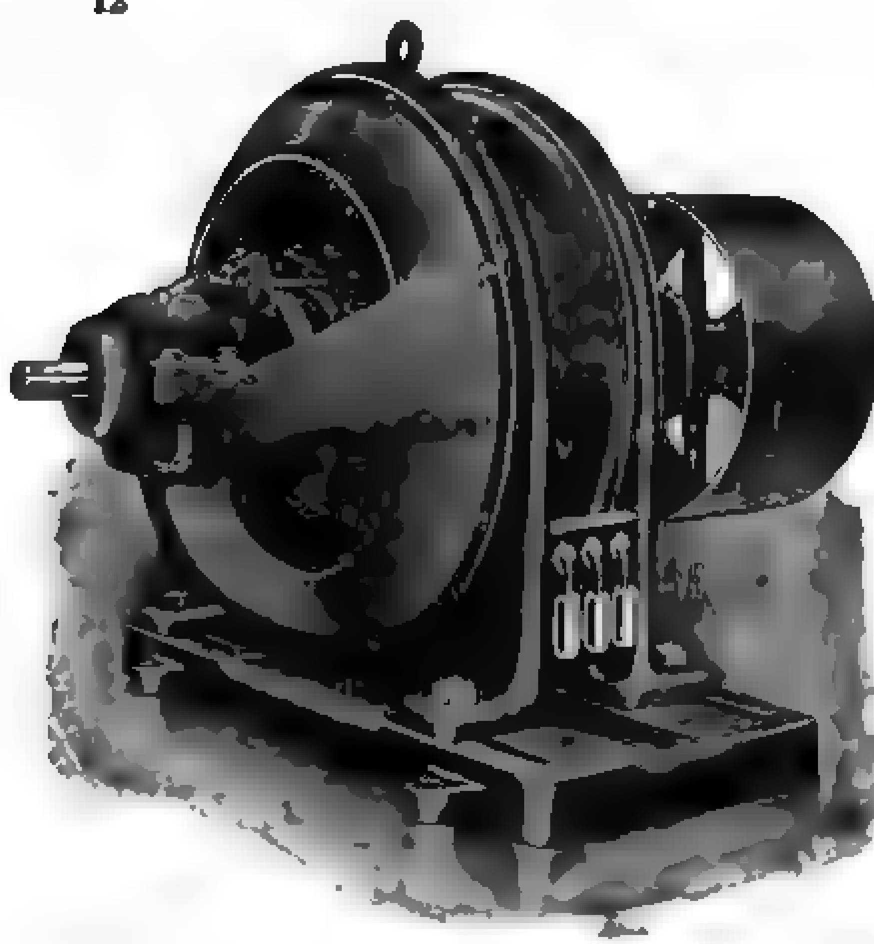


FIG. 1,384.—Fort Wayne revolving field belt driven alternator. It is designed for belted exciter, having a shaft extension at the collector ring end for exciter driving pulley.

Horse power transmitted per inch width of double belt at 4,188 feet speed

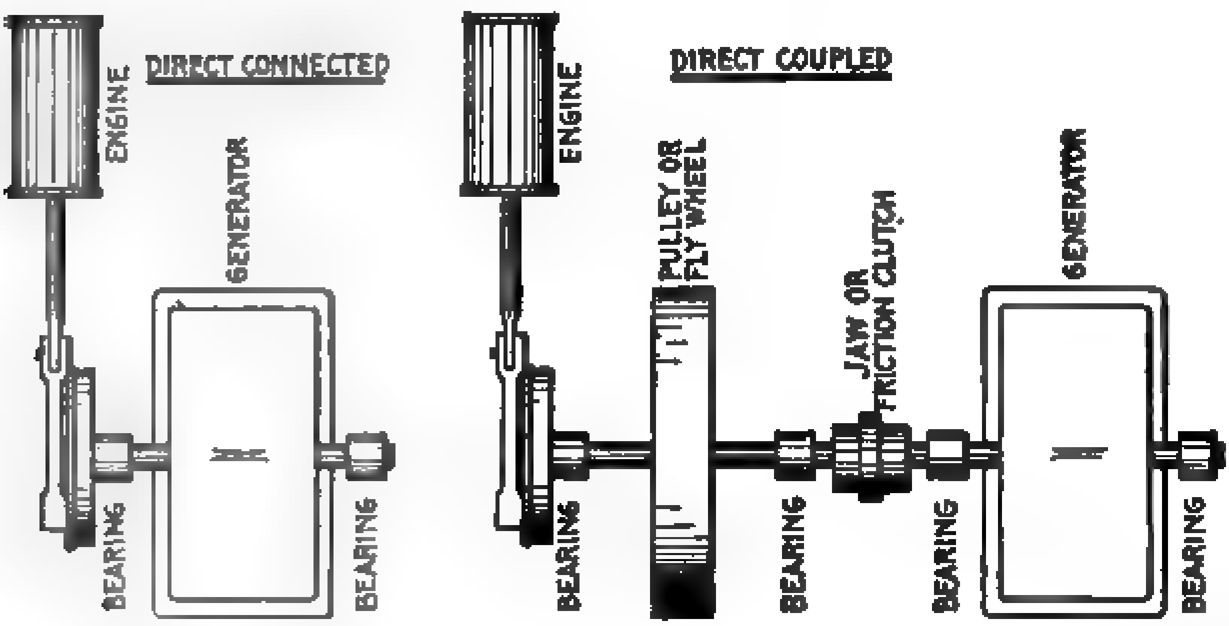
$$2 \times \frac{4{,}188}{1{,}000} = 8.38.$$

Width of double belt for 50 horse power

50 ÷ 8.38 = 5.97, say 6 inch.

Ques. What are the advantages of chain drive?

Ans. The space required is much less than with belt drive, as the distance between centers may be reduced to a minimum. It is a positive drive, that is, there can be no slip. Less liability of becoming detached, and, because it is not dependent on



FIGS. 1,385 and 1,386.—Diagram showing the distinction between *direct connected* and *direct coupled* units. In a direct connected unit, fig. 1,385, the engine and generator are permanently connected on one shaft, there being one bed plate upon which both are mounted. An engine and generator are said to be direct coupled when each is independent, as in fig. 1,386, being connected solely by a jaw or friction clutch or equivalent at times when it is desired to run the generator. At other times the generator may be disconnected and the engine run to supply power for other purposes.

frictional contact, the diameters of the sprockets may be much less than pulley diameter for belt drive.

Ques. What are some objections?

Ans. A lubricant is required for satisfactory operation, which causes more or less dirt to collect on the chain, requiring

frequent cleaning; climbing of teeth when links and teeth become worn; noise and friction.

Direct Connected Alternators.—There are a large number of cases where economy of space is of prime importance, and to meet this condition the alternator and engine are direct con-

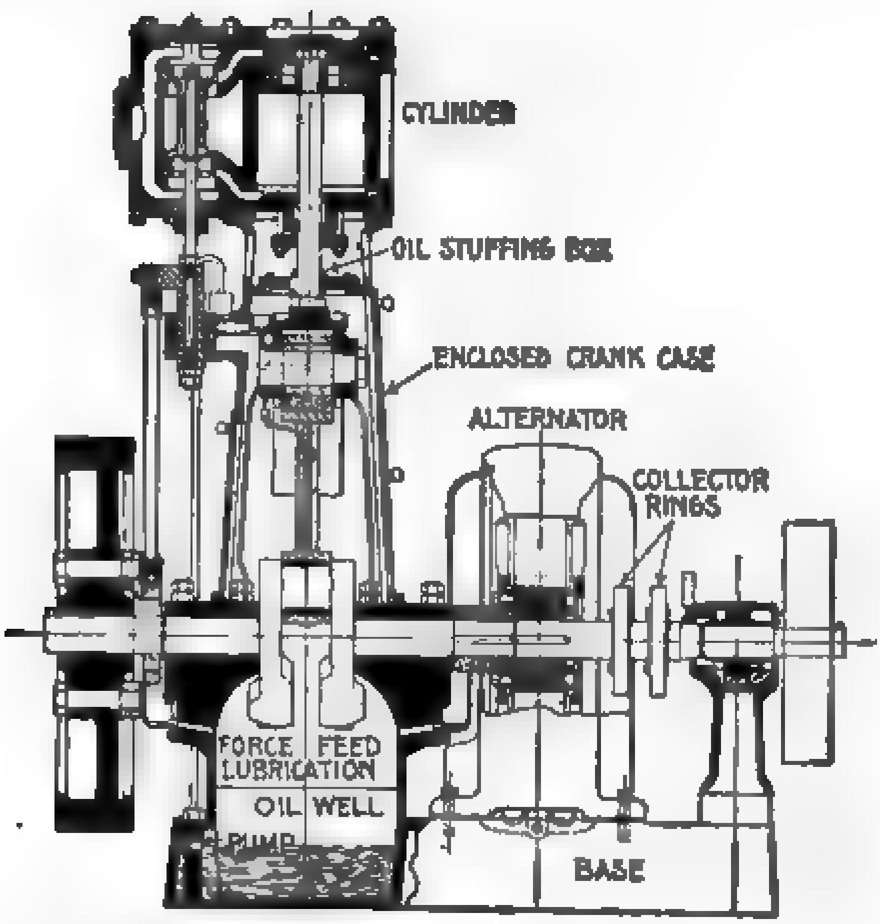


FIG. 1,287.—Endberg direct-connected, or "engine type" alternator. In many places direct connected units are used, owing to the great saving in floor space, convenience of operation, and absence of belts.

nected, meaning, that there is no intermediate gearing such as belt, chain, etc., between engine and alternator.

One difficulty encountered in the direct connection of engine and alternator is the fact that the most desirable rotative speed of the engine is less than that of the alternator. Accordingly a compromise is made by raising the *engine speed and lowering* the alternator speed.

The insistent demand for direct connected units in the small and medium sizes, especially for direct current units, was the chief cause resulting in the rapid and high development of what is known as the "high speed automatic engine."

Increasing the engine speed means that more horse power is developed for any given cylinder dimensions, while reducing the speed of the generator involves that the machine must be larger for a given output, and in the case of an alternator more poles are required to obtain a given frequency, resulting in increased cost.

The compactness of the unit as a whole, simplicity, and general advantages are usually so great as to more than offset any additional cost of the generator.

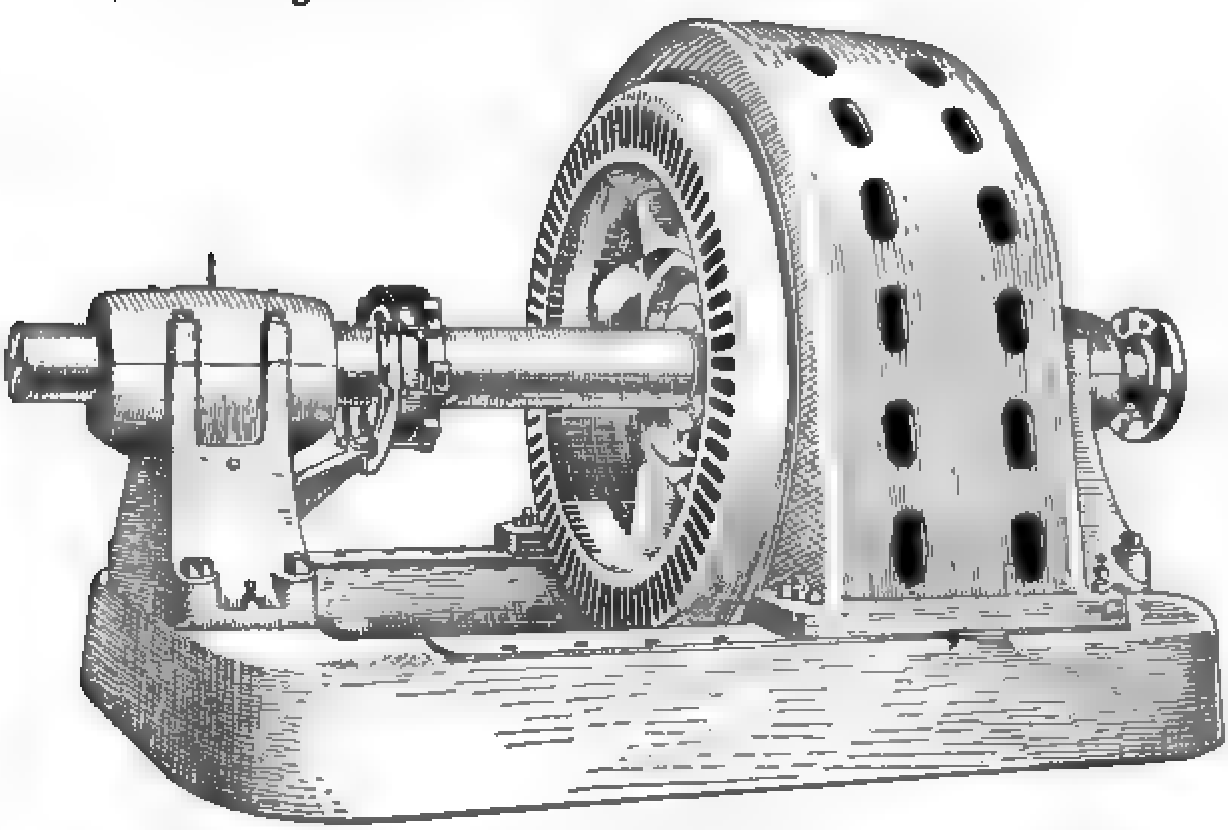


Fig. 1,338.—Crocker-Wheeler 2,000 kva 2,400 volt coupled type alternator. The coupled type of alternator is desirable for use with steam, gas, and oil engines, and water wheels where it is inconvenient to mount the alternator on the engine shaft or to extend the engine base to accommodate a bearing. This type consists of alternator complete with shaft and bearings similar to belt type machines, but with bearings not necessary designed for the side pull of belts.

Ques. What is the difference between a direct connected and a direct coupled unit?

Ans. A direct connected unit comprises an engine and *generator permanently* connected; direct coupling signifies that

engine and generator are each complete in itself, that is, having two bearings, and are connected by some device such as friction clutch, jaw clutch, or shaft coupling.

Revolving Armature Alternators.—This type of alternator is one which has its parts arranged in a manner similar to a dynamo, that is, the armature is mounted on a shaft so it can

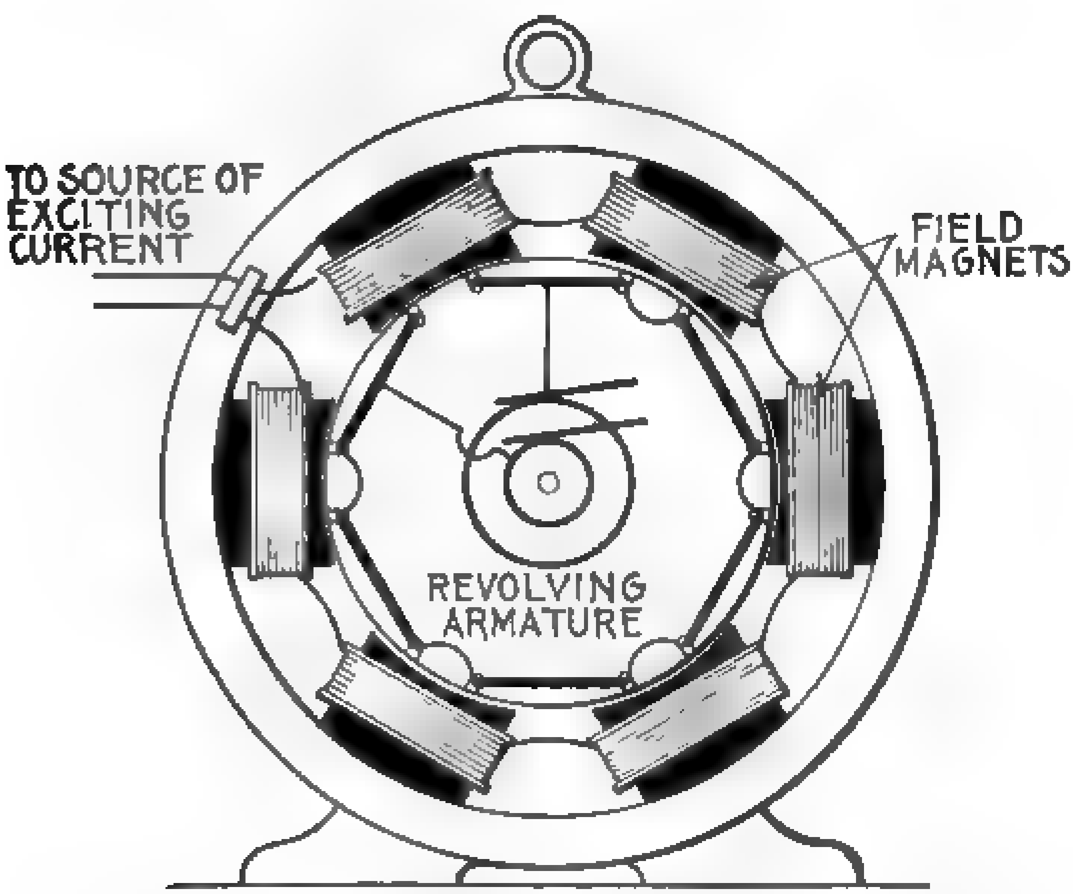


Fig. 1,389.—Revolving armature alternator. Revolving armatures are suitable for machines generating current at comparatively low pressure, as no difficulty is experienced in collecting such current. Revolving armature alternators are also suitable for small power plants, isolated lighting plants, where medium or small size machines are required.

revolve while the field magnets are attached to a circular frame *and arranged radially around* the armature, as shown in fig. *1,389. It may be single or polyphase, belt driven, or direct connected.*

Ques. When is the revolving type of armature used and why?

Ans. It is used on machines of small size because the pressure generated is comparatively low and the current transmitted by the brushes small, no difficulty being experienced in collecting such a current.

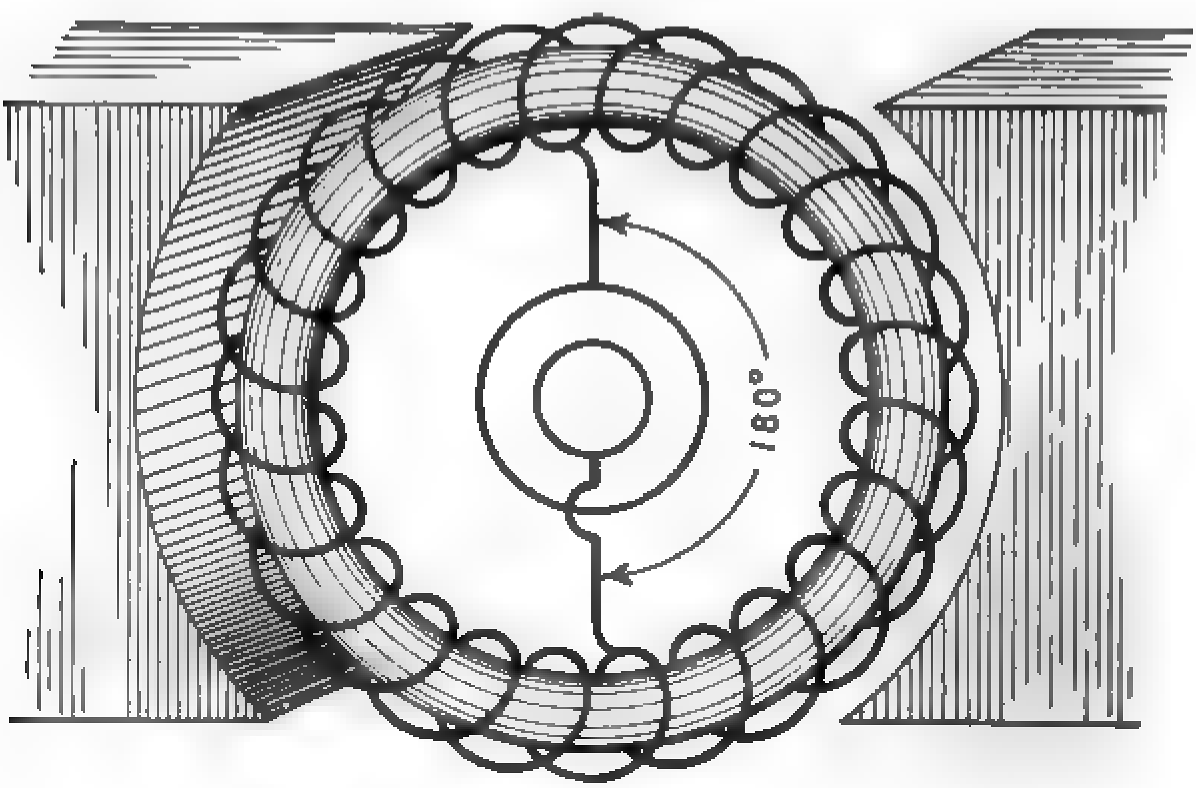


FIG. 1,390.—Ring wound dynamo arranged as alternator by replacing commutator with collector rings connected to the winding at points 180° apart.

Ques. Could a dynamo be converted into an alternator?

Ans. Yes.

Ques. How can this be done?

Ans. By placing two collector rings on one end of the armature and connecting these two rings to points in the armature *winding 180°* apart, as shown in fig. 1,390.

Ques. Would such arrangement as shown in fig. 1,390 make a desirable alternator?

Ans. No.

Alternating current windings are usually different from those used for direct currents. One distinction is the fact that a simple open coil winding may be, and often is, employed, but the chief difference is the intermittent action of the inductors.

In a direct current Gramme ring winding a certain number of coils are always active, while those in the space between the pole pieces are not generating. In this way a practically steady pressure is produced by a large fraction of the coils.

In the case of an alternator all of the coils are either active or inactive at one time. Hence, the winding need cover only as much of the armature as is covered by the pole pieces.

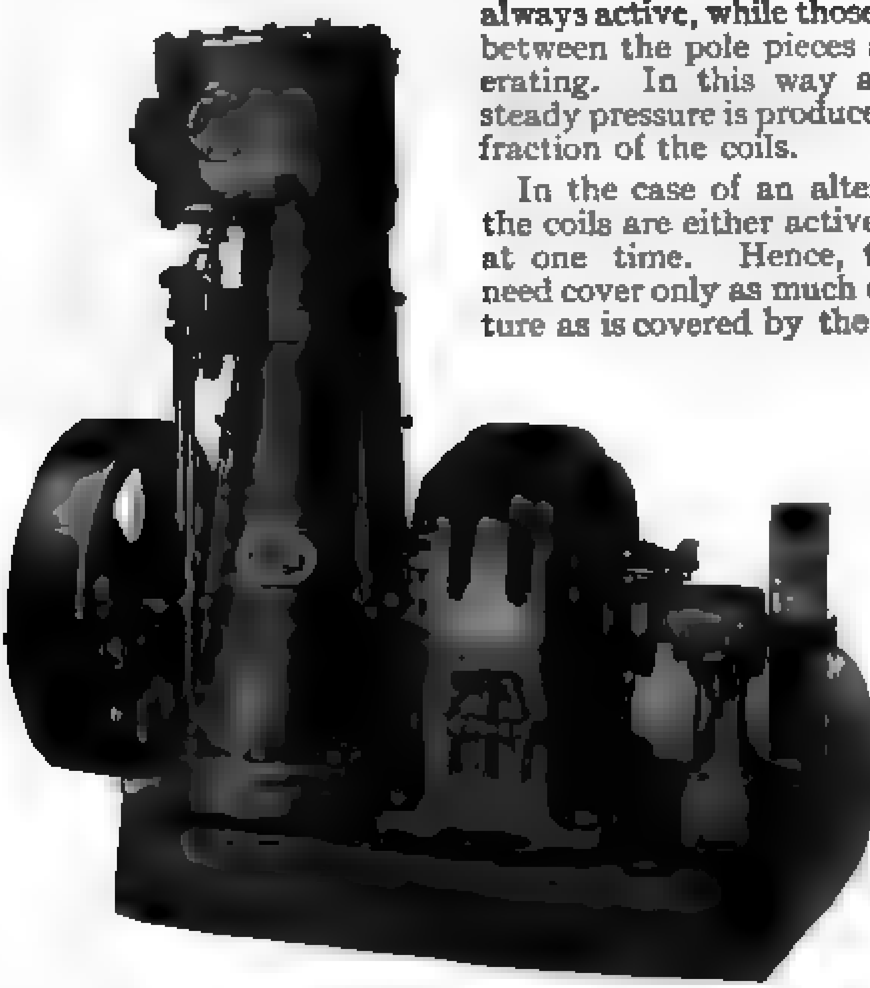


FIG. 1,391.—Engberg alternating current generating set; shown also in cross section in fig. 1,387. The set comprises a vertical engine and alternator, direct connected and placed on one base. The lubrication system comprises an oil pump situated in the base of the engine, pumping the oil from an oil reservoir up into a sight feed oil cup which leads to a distributing oil trough on the inside of the engine frame, from here oil pipes lead to all movable bearings, which are grooved to insure proper distribution of oil. The oil is drained from bearings into the base, filtered and repumped. A water shed partition is provided in the engine frame, preventing any water passing from the cylinder down into the engine base and mixing with the oil, consequently leaving good, clean oil in the oil reservoir at all times. *The details of the lubrication system are shown in fig. 1,381.*

Revolving Field Alternators.—In generating an elect current by causing an inductor to cut magnetic lines, it mal no difference whether the cutting of the magnetic lines is effect by moving an inductor across a magnetic field or moving t magnetic field across the inductor.

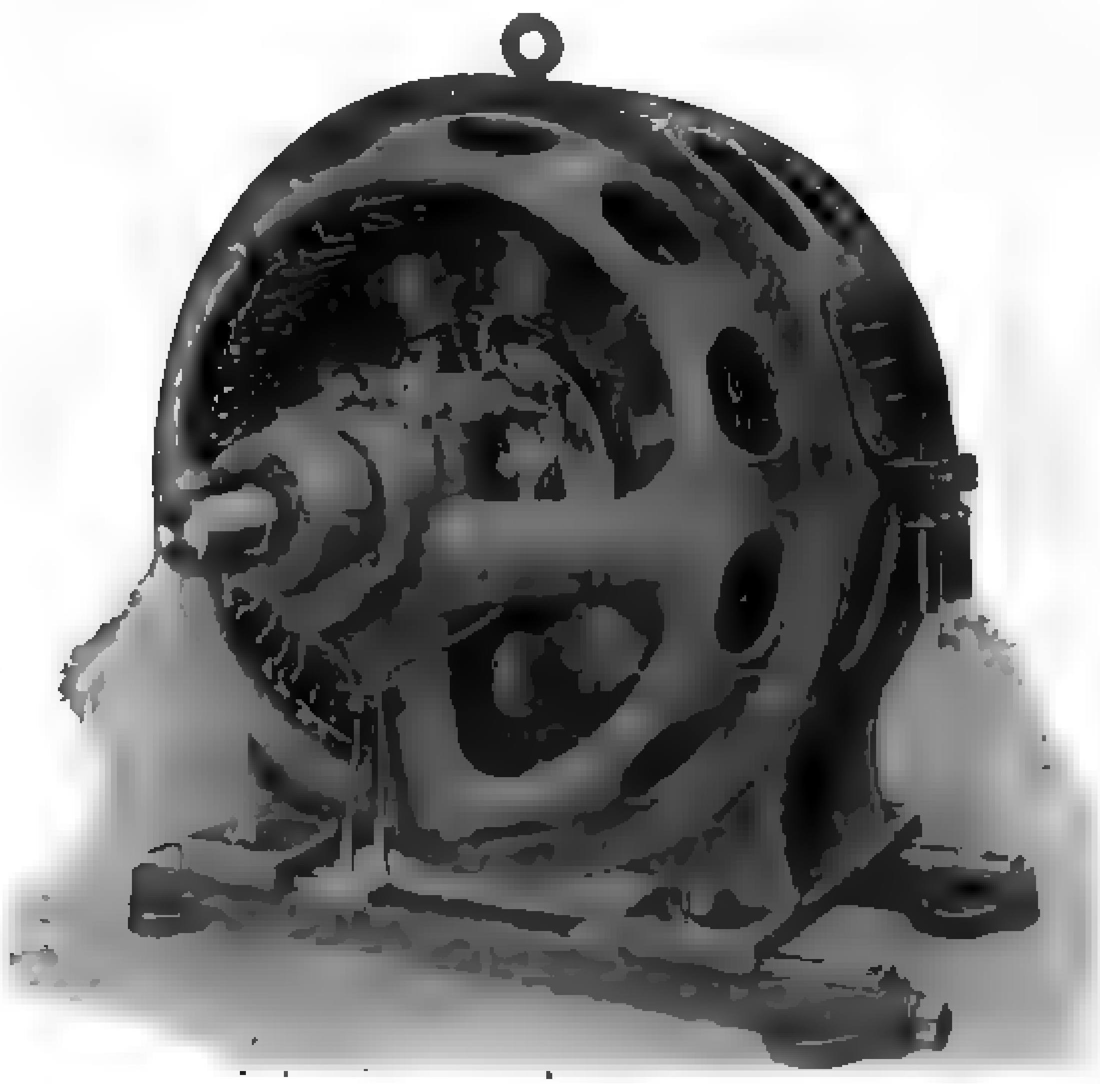


FIG. 1,392.—Allis-Chalmers revolving field self-contained belted type alternator.

Motion is purely a relative matter, that is, an object *said to move when* it changes its position with some other ob *regarded as* stationary; it may be moving with respect

second object, and at the same time be at rest with respect to a third object. Thus, a dory has a speed of four miles per hour in still water; if it be run up stream against a current flowing four miles per hour it would move at that speed with respect to the water, yet remain at rest with respect to the earth.

It must be evident then that motion, as stated, being a purely relative matter, it makes no difference whether the armature

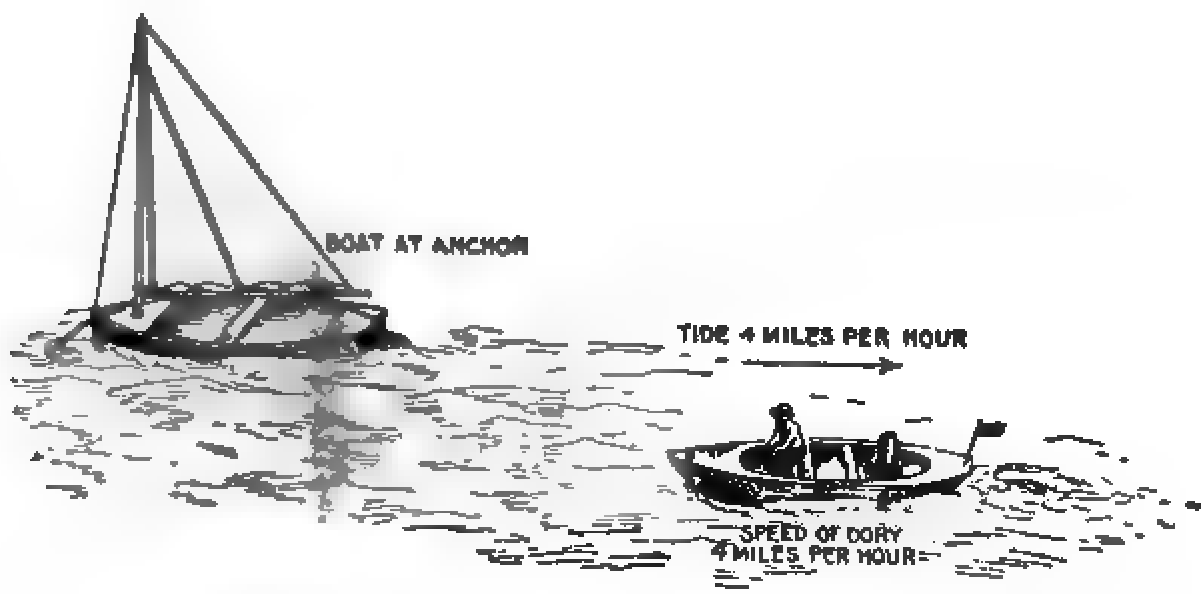


FIG. 1,393.—Marine view, showing that motion is purely a relative matter. In order that there may be motion something must be regarded as being stationary. In the above illustration a catboat is shown at anchor in a stream which is flowing at a rate of four miles per hour in the direction of the arrow. The small dory running at a speed of four miles per hour against the current is *moving* at that velocity *relative* to the current, yet is at a standstill relative to the catboat. In this instance both catboat and dory are moving with respect to the water if the latter be regarded as stationary. Again if the earth be regarded as being stationary, the two boats are at rest and the water is moving relative to the earth.

of a generator move with respect to the field magnets, or the field magnets move with respect to the armature, so far as inducing an electric current is concerned.

For alternators of medium and large size there are several reasons why the armature should be stationary and the field ***magnets revolve, as follows:***

1. By making the armature stationary, superior insulation methods may be employed, enabling the generation of current at very much higher voltage than in the revolving armature type.

2. Because the difficulty of taking current at very high pressures from collector rings is avoided.

The field current only passes through the collector rings. Since the field current is of low voltage and small in comparison with the main current, small brushes are sufficient and sparking troubles are avoided.

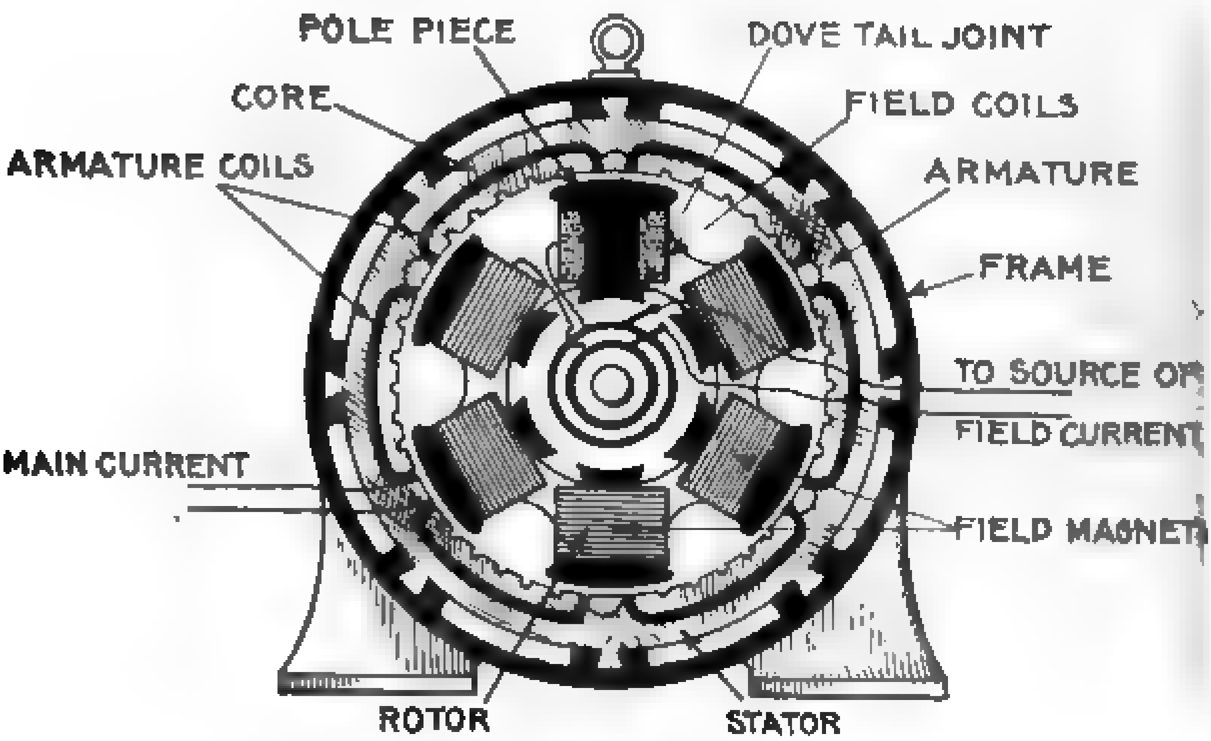


Fig. 1,394.—Diagram showing essential parts of a revolving field alternator and method of joining the parts in assembling.

3. Only two collector rings are required.

4. The armature terminals being stationary, may be enclosed ermanently so that no one can come in contact with them.

Ques. What names are usually applied to the arma-re and field magnets with respect to which moves?

Ans. ***The "stator" and the "rotor."***

The terms armature and field magnets are to be preferred to such expressions. An armature is an armature, no matter whether it move or be fixed, and the same applies to the field magnets. There is no good reason to apply other terms which do not define the parts.

Ques. Explain the essential features of a revolving field alternator.

Ans. The construction of such alternators is indicated in the diagram, fig. 1,394. Attached to the shaft is a field core, which carries the latter, consisting of field coils fitted on pole pieces which are dovetailed to the field core. The armature is built into the frame and surrounds the magnets as shown. The field current, which is transmitted to the magnets by slip rings and brushes, consists of direct current of comparatively low pressure, obtained from some external source.

FIG. 1,395.—Western Electric stationary armature and frame of engine driven alternator. It is of cast iron and surrounds the laminated iron core in which the armature windings are embedded. Heavy steel clamping fingers hold the core punchings in place and numerous ventilating ducts are provided in the core at frequent intervals to allow free circulation of cool air. The armature coils are form wound, insulated, and retained in the core slots by means of wedges.

[redacted]

Inductor Alternators.—In this class of alternator armature and field magnets are stationary, a current induced in the armature winding by the action of a so inductor in moving through the magnetic field so as to perio vary its intensity.

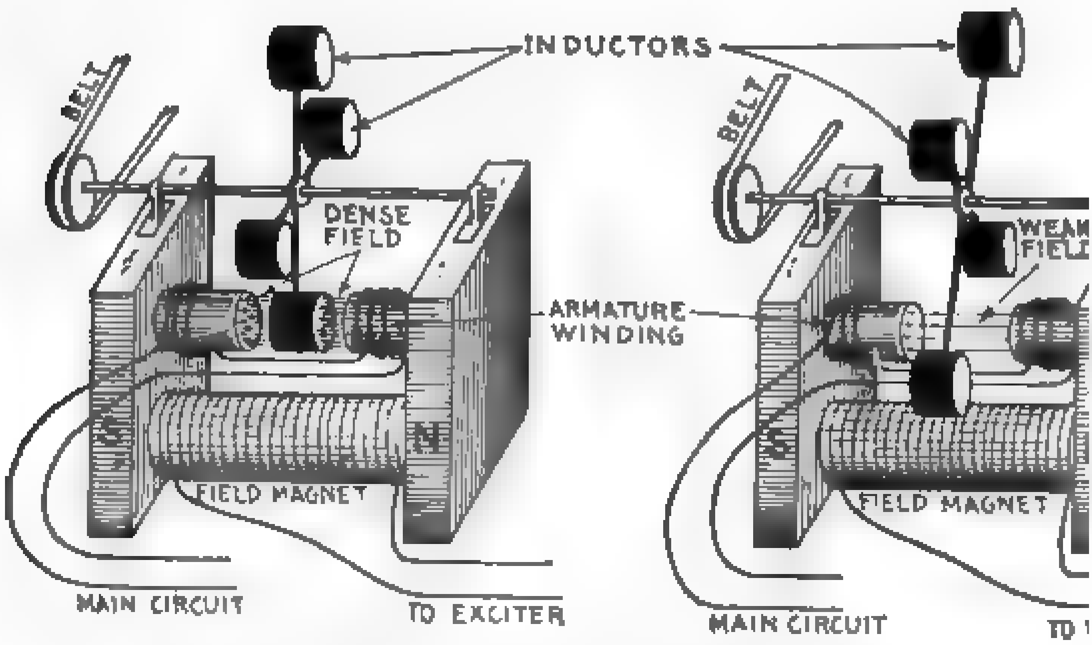


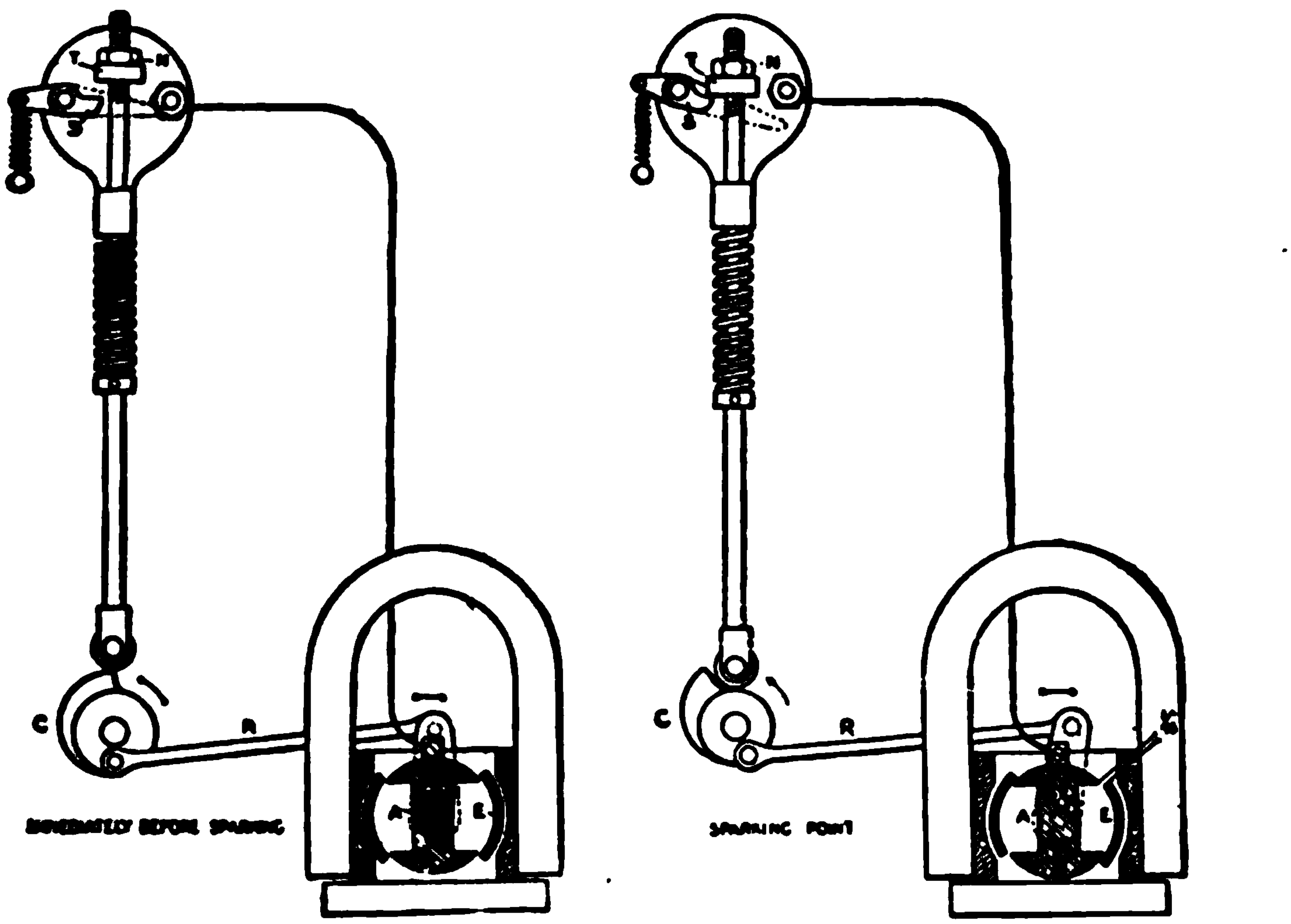
FIG. 1,396 and 1,397.—Elementary inductor alternator; diagram showing pri operation. It consists of a field magnet, at the polar extremities of which is an winding both being stationary as shown. Inductors consisting of iron discs are on a shaft to rotate through the air gap of the magnet poles. Now in the rotati inductors, when any one of them passes through the air gap as in fig. 1,396, the relu magnetic resistance of the air gap is greatly reduced, which causes a correspo crease in the number of magnetic lines passing through the armature winding. an inductor passes out of the air gap as in fig. 1 397, the number of magnetic lines reduced; that is, when an inductor is in the air gap, the magnetic field is dense, no inductor is in the gap, the field is weak; a variable flux is thus made to pass th armature winding, inducing current therein. The essential feature of the induc nator is that iron only is revolving, and as the design is usually homopolar, the flux in its field coils is not alternating but undulating in character. Thus, wit maximum flux through each polar mass, the total number of armature turns re produce a given voltage is just twice that which is required in an alternator alternating instead of an undulating flux through its field windings. The above one shown in figs. 1 398 and 1,399 are examples of real inductor alternators, those the other cuts are simply so called inductor alternators, the distinction being that, the *inductor* constitutes no part of the field magnet.

Ques. What influence have the inductors on th flux?

Ans. They cause it to undulate; that is, the flux rise *maximum and falls* to a minimum value, but does not rev

Ques. How does this affect the design of the machine as compared with other types of alternator?

Ans. With a given maximum magnetic flux through each polar mass, the total number of armature turns necessary to produce a given pressure is twice that which is required in an alternator having an alternating flux through its armature windings.



FIGS. 1,398 and 1,399.—A low tension ignition system with an inductor magneto of the oscillating type. The inductor E is rotated to and fro by means of a link R, one end of which is attached to the inductor crank, and the other to the igniter cam C. Two views are shown: immediately before and after sparking. S is the grounded electrode of the igniter; T an adjustable hammer which is secured in position by a lock nut N.

Ques. Is the disadvantage due to the necessity of doubling the number of armature turns compensated in any way?

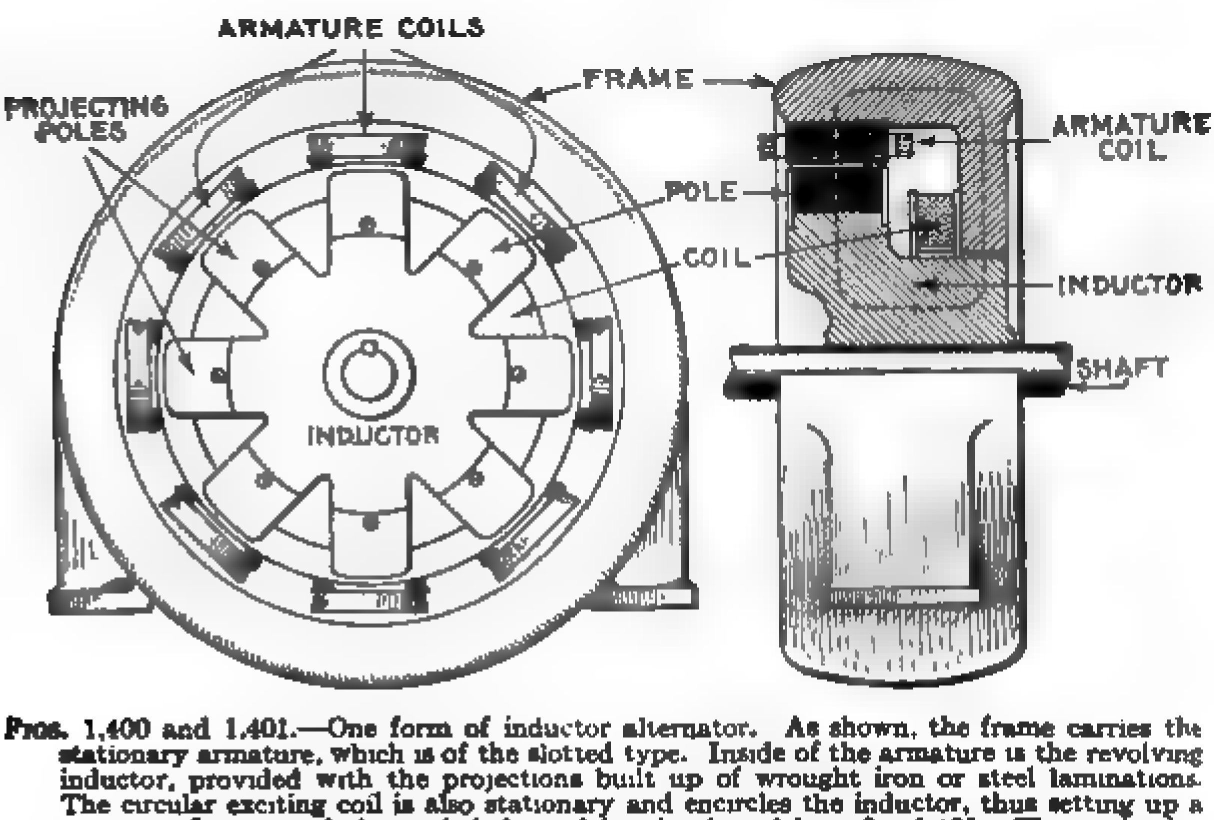
Ans. Yes, the magnetic flux is not reversed or entirely changed in each *cycle through* the whole mass of iron in the

armature, the abrupt changes being largely confined to the projections on the armature surface between the coils.

Ques. What benefit results from this peculiarity?

Ans. It enables the use of a very high magnetic flux density in the armature without excessive core loss, and also the use of a large flux without an excessive increase in the amount of magnetic iron.

The use of a large flux permits a reduction in the number of armature turns, thus compensating, more or less, for the disadvantage due to the operation of only one-half of the armature coils at a time.

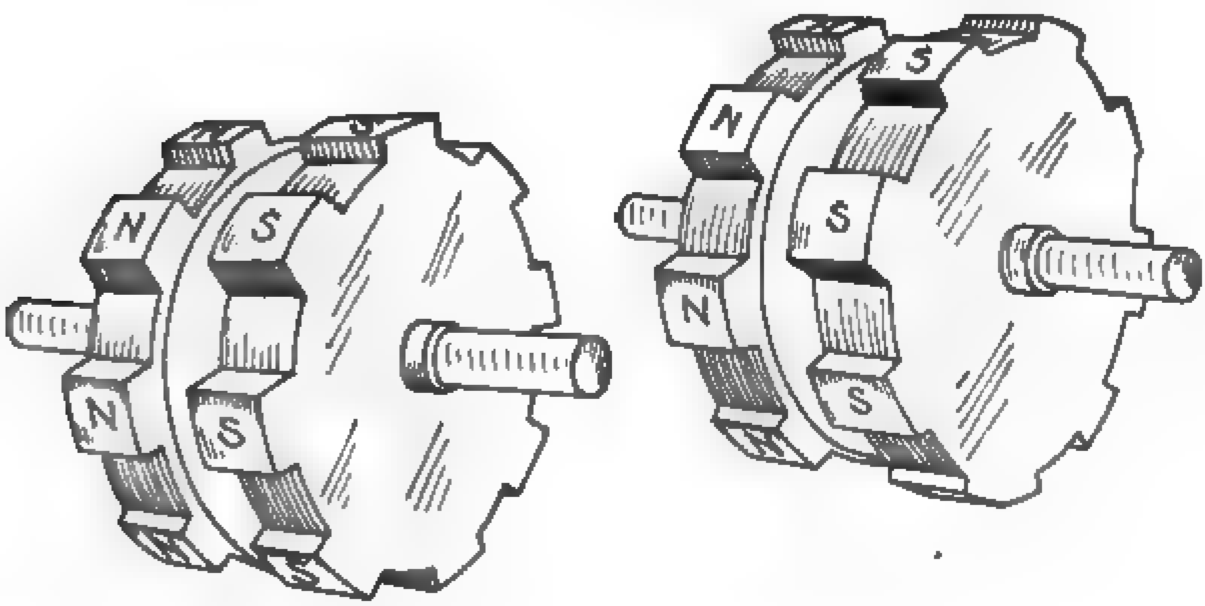


FIGS. 1,400 and 1,401.—One form of inductor alternator. As shown, the frame carries the stationary armature, which is of the slotted type. Inside of the armature is the revolving inductor, provided with the projections built up of wrought iron or steel laminations. The circular exciting coil is also stationary and encircles the inductor, thus setting up a magnetic flux around the path indicated by the dotted line, fig. 1,401. The projecting poles are all, therefore, of the same polarity, and as they revolve, the magnetic flux sweeps over the coils. Although this arrangement does away with collector rings, the machines are not so easily constructed as other types, especially in the large sizes. The magnetizing coil becomes large and difficult to support in place, and would be hard to repair in case of breakdown. Inductor alternators have become practically obsolete, except in special cases, as inductor magnetos used for ignition and other purposes requiring a very *small size machine*. The reasons for the type being displaced by other forms of alternator *are chiefly because only half* as great a pressure is obtained by a flux of given amount, *as would be obtained* in the ordinary type of machine. It is also more expensive to build *two armatures, to give* the same power, than to build one armature. This type has still *other grave defects*, among which may be mentioned enormous magnetic leakage, heavy *eddy current losses, inferior heat emissivity*, and bad regulation.

Classes of Inductor Alternator.—There are two classes into which inductor alternators may be divided, based on the mode of setting of their polar projections:

1. Homopolar machines;
2. Heteropolar machines.

Homopolar Inductor Alternators.—In this type the positive polar projections of the inductors are set opposite the negative polar projections as shown in fig. 1,402. When the polar projections are set in this manner, the armature coils must be "staggered" or set displaced along the circumference with respect to one another at a distance equal to half the distance from the positive pole to the next positive pole.



FIGS. 1,402 and 1,403.—Homopolar and heteropolar "inductors". Homopolar inductors have their N and S poles opposite each other, while in the heteropolar type, they are "staggered" as shown.

Heteropolar Inductor Alternators.—Machines of this class are those in which the polar projections are themselves staggered, as shown in fig. 1,403, and therefore, do not require the staggering of the armature coils. In this case, a single armature of double width may be used, and the rotating inductor then acts as a *heteropolar magnet*, or a magnet which presents alternatively positive and negative poles to the armature, instead of presenting a series of poles of the same polarity as in the case of a *homopolar magnet*.

Use of Inductor Alternators.—Morday originally designed and *introduced inductor alternators* in 1866. They are not the prevailing *type, as their field of application* is comparatively narrow. They have *to be very carefully designed* with regard to magnetic leakage in ord

to prevent them being relatively too heavy and costly for their output, and too defective with respect to their pressure regulation, other defects being heavy eddy current losses and inferior heat conductance.

Hunting or Singing in Alternators.—Hunting is a term applied to the state of two parallel connected alternators running out of step, or not synchronously, that is, "see sawing." When

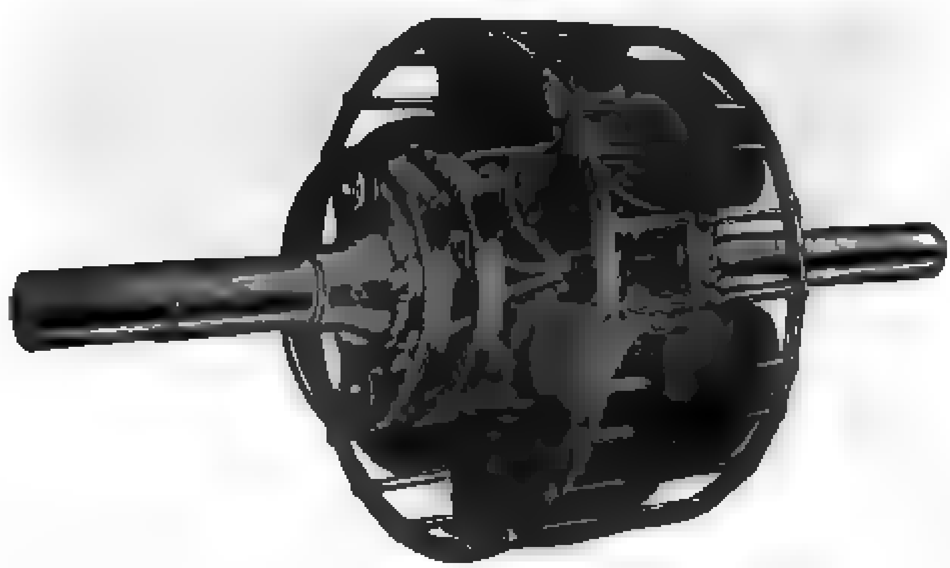


FIG. 1,404.—Revolving field of Fort Wayne alternator equipped with *amortisseur winding* The object of this winding is to check any tendency toward *hunting* when the alternator is to be run as a synchronous motor, either for rotary condenser or power service. The amortisseur winding consists of heavy copper bars, placed around and through the pole faces and short circuited at the ends by heavy copper rings; it serves as a starting winding to bring the rotor up to speed as an induction motor, and also serves as a damping device to neutralize any tendency toward "hunting" caused by variation in speed of the generator supplying the current.

the current wave of an alternator is peaked and two machines are operated in parallel it is very difficult to keep them in step, that is in synchronism. Any difference in the phase relation which is set up by the alternation will cause a local or synchronizing current to flow between the two machines and at times it becomes so great that they must be disconnected.

Alternators which produce a smooth current wave and are maintained at uniform speed by properly designed governors,

operate fairly well in parallel, but are not entirely free from hunting, and other means are provided to overcome the difficulty.

When heavy copper flanges, called dampers, are put over the polar projections or copper bars laid in grooves on the pole face and short circuited by connecting rings (called amortisseur

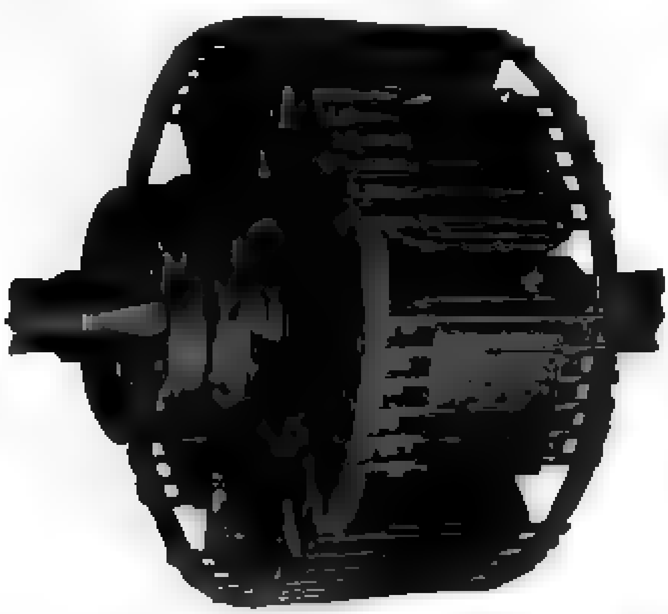


FIG. 1,405.—Westinghouse field with amortisseur or "damper" winding for 75 kva. and larger belted alternators, which prevents hunting and reduces eddy currents in the pole pieces. The copper bars of the amortisseur cage winding are arranged in partially closed slots in the pole pieces.

winding), the powerful induced currents which are produced when the alternators get out of step tend to quickly re-establish the phase relation.

Two examples of a field provided with amortisseur winding is shown in figs. 1,404 and 1,405.

NOTE.—Amortisseur windings are often erroneously called "squirrel cage" windings on account of similarity of construction. The latter term should be reserved for its proper significance as being the name of the type of armature winding generally used for induction motors, the name being suggested by the resemblance of the finished armature to the wheel of a squirrel cage. A comparison of figs. 1,405 and 1,746 will show the distinction. In a squirrel cage winding there is a large number of bars uniformly spaced; an amortisseur winding consists of a comparatively small number of bars, usually unevenly spaced, that is they are divided into groups with considerable space between the groups, as in fig. 1,405, and less pronounced in fig. 1,404. The bars are short circuited by rings the same as in squirrel cage windings.

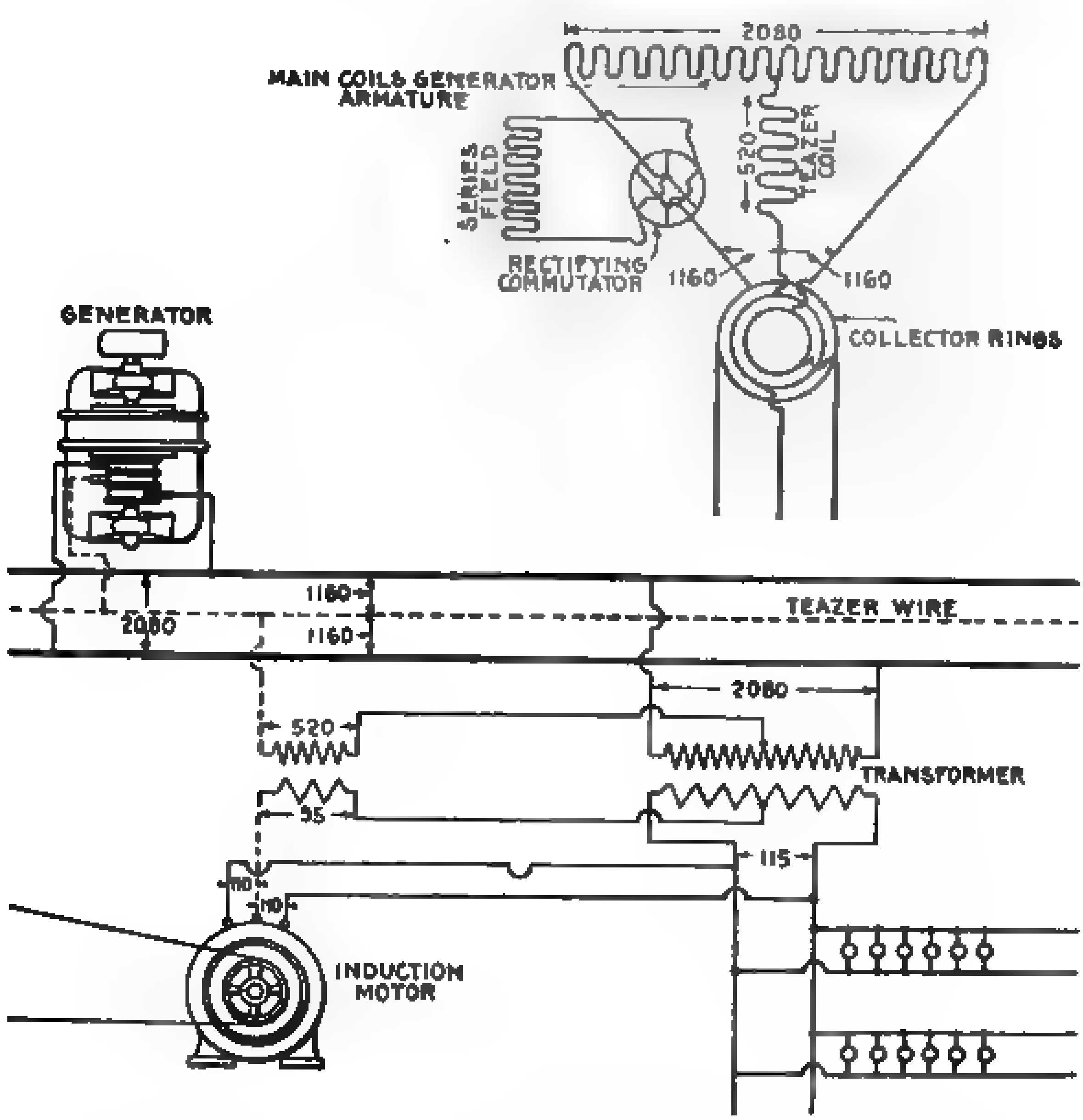


FIG. 1,406.—Diagram of monocyclic system, showing monocyclic armature and transformer connections. The monocyclic system is a single phase system primarily intended for the distribution of lights with an incidental load of motors. The lighting load is entirely connected to one single phase circuit, and the motors are started and operated from this circuit with the assistance of the teazer wire. The long coil indicates the main winding of the armature, which is similar in its arrangement and size to the ordinary armature winding of a single phase alternator. The short coil which connects at one end to the middle point of the coil above mentioned, and at the other to a third collector ring is called the "teazer" coil. Its use is to generate a pressure in quadrature with that of the main coil. This pressure is combined with the main pressure of the alternator by transformers, so as to give suitable phase relations for operating induction motors. In the diagram the voltage has been assumed to be 2,080 volts, and the voltages marked to correspond with the generated pressure. The coils of the alternator armature are connected, as shown, to two main leads and to a teazer wire. Between each end of the main coil and the end of the teazer coils, a resultant pressure is generated. These resultants are about 12 per cent. larger than half the main pressure. They also have a phase difference.

Monocyclic Alternators.—This type of alternator was designed prior to the introduction of the polyphase systems, to overcome the difficulties encountered in the operation of single phase alternators as motors. A single phase alternator will not start from rest as a motor, but must first be started and brought

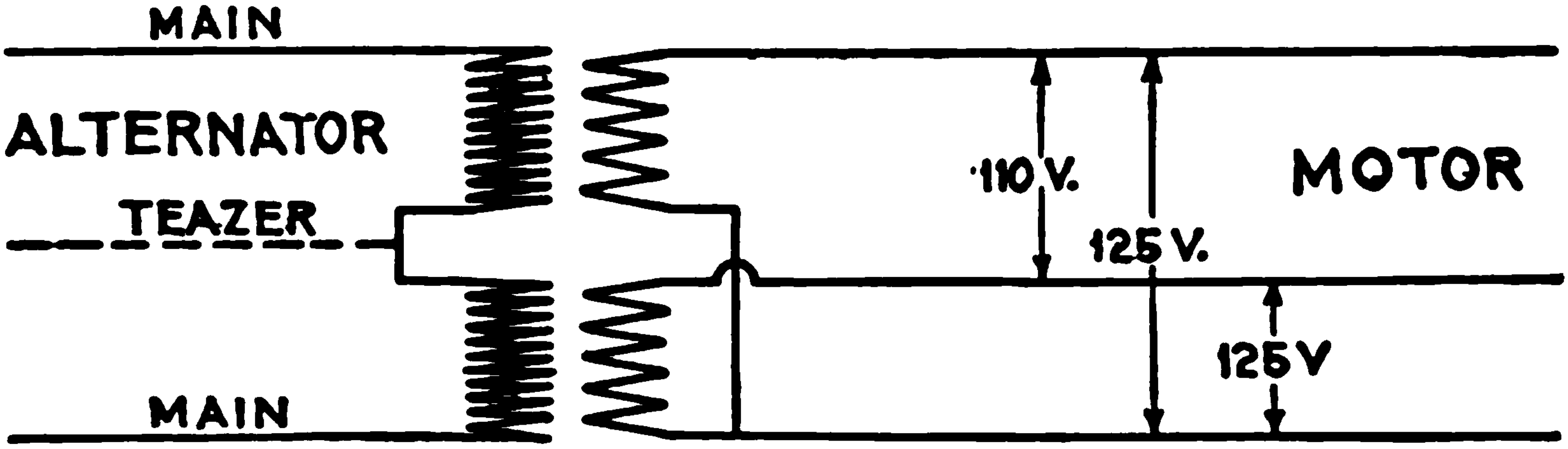


FIG. 1,407.—Monocyclic system diagram showing transformer connections.

up to the proper speed before being connected with single phase mains. This condition constituted a serious difficulty in all cases where the motor had to be stopped and started at comparatively frequent intervals.

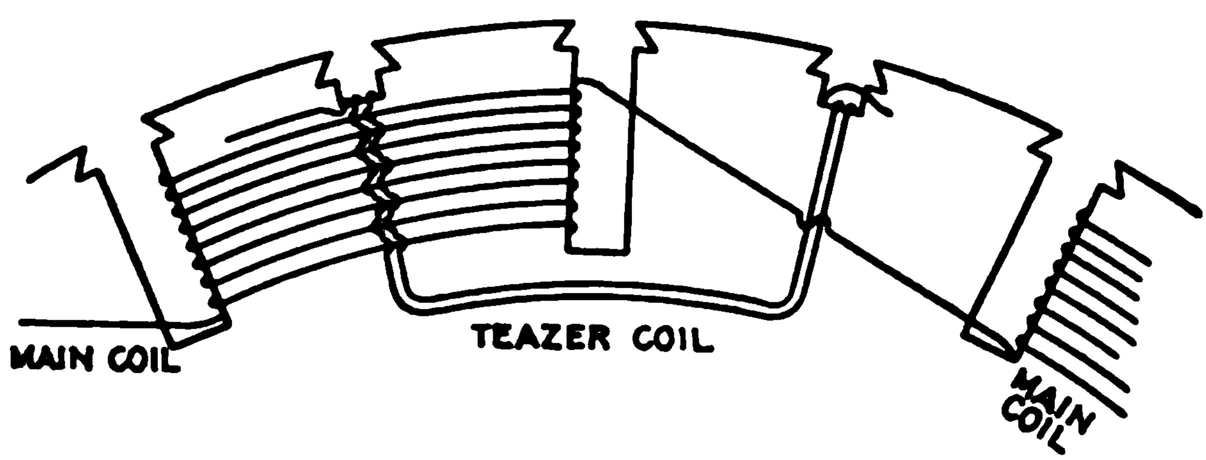


FIG. 1,408.—Diagram showing section of monocyclic alternator armature illustrating the armature winding. The main coils are wound on every other tooth, and the teaser coils are placed in quadrature with them, as shown.

The monocyclic alternator is a single phase machine provid with an additional coil, called a *teaser coil*, wound in two pha relationship with, and connected to the center of the main sin

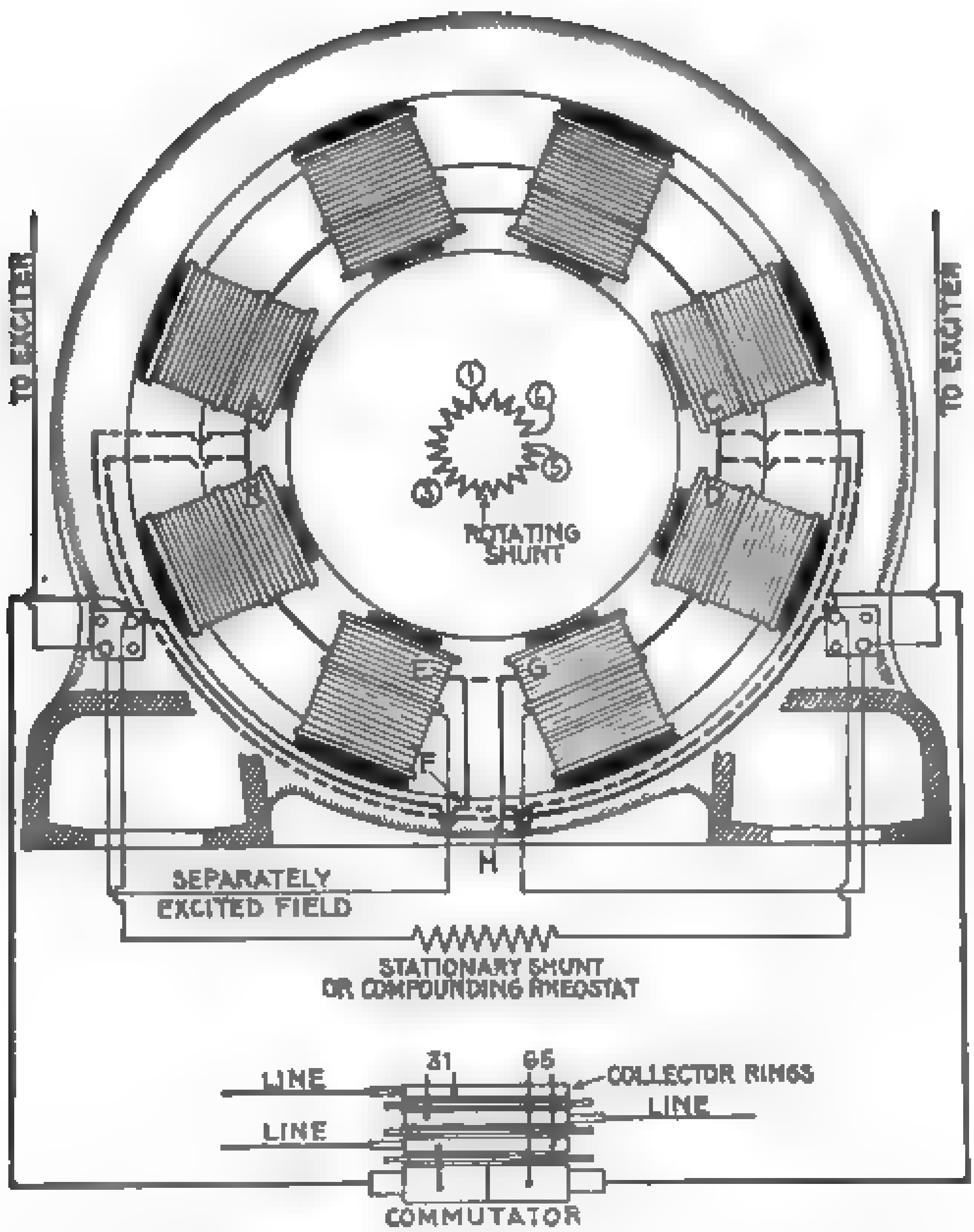


FIG. 1,409.—Diagram showing connections of General Electric Monocyclic alternator. I 2,300 volt machine, connect as shown by solid lines. For 1,150 volt machine, omit c nections A to B, C to D, E to F, and G to H, and connect as shown by dotted lines. T armature of a standard monocyclic alternator rotates in a counter clockwise direct facing the commutator. When the alternator is loaded, the voltage between the tea coil and the two terminals of the main coil may be different; therefore, it is necessary have the commutator connected in corresponding ends of the main coil. If the mach has not been arranged for clockwise rotation, the following change in the connections the commutator-collector must be made if the machine is to be run in parallel with anoth Fig. 1,410 shows the connections of monocyclic alternators. In fig. 1,409, the studs on commutator-collector marked 1 and 6 are the terminals of the main coil. These shou be reversed. The numbers are stamped on the ends of the stud and may be seen w the assistance of a mirror. By reference to this diagram it is a simple matter to trace the connections with a magneto, after the armature leads are disconnected and the brus raised.

phase coil. It is provided with three collector rings; two for the single phase coil, and one for the free end of the *teaser coil.*

By this arrangement ordinary single phase incandescent lighting can be accomplished by means of a single pair of wires taken from the single phase coil. Where three phase motors have to be operated, however, a third wire, called the *power wire,* which is usually smaller than the main single phase wires is carried

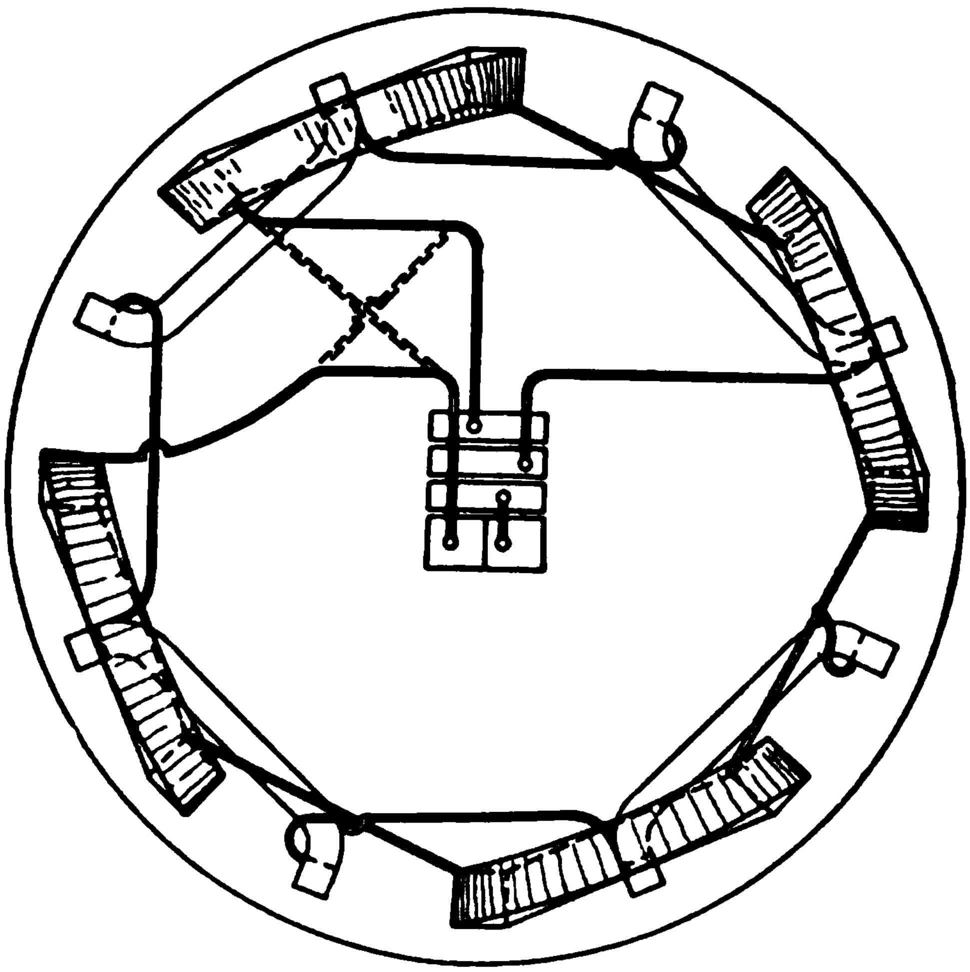
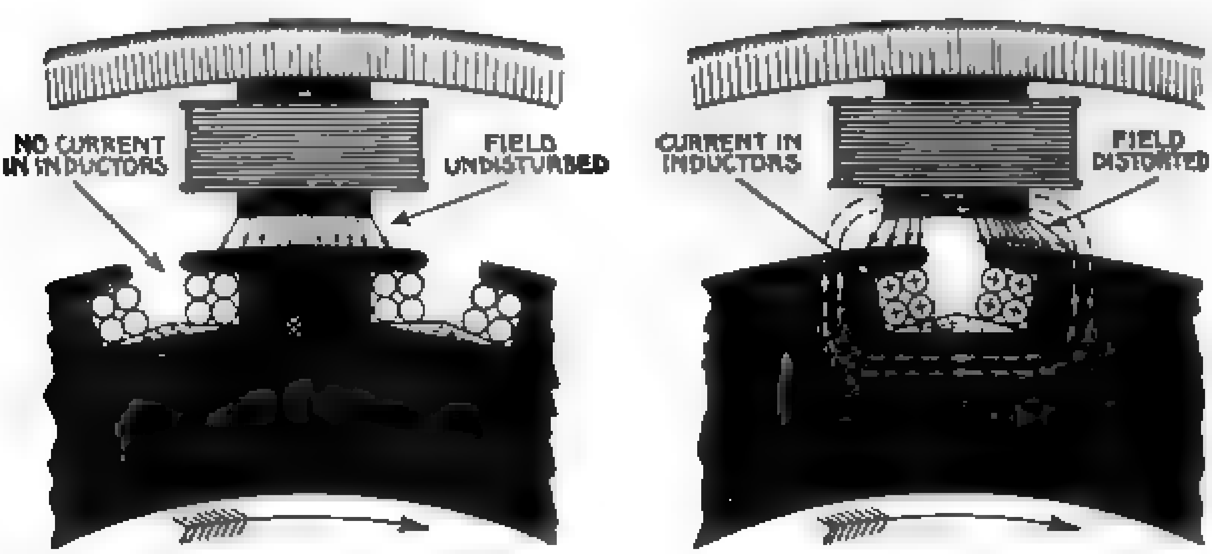


Fig. 1,410.—Diagram showing connections of General Electric monocyclic alternator. The solid lines show standard connections for counter-clockwise rotation; the broken lines show connection changed for clockwise rotation.

to the point at which the motor is located, and by the use of two suitably connected transformers three phase currents are obtained from the combined single phase and power wires for operating the motors.

Fig. 1,406 shows the connections of the monocyclic system and it is only necessary to carry the teaser wire into buildings where motors are to be used.

Armature Reaction.—Every conductor carrying a current creates a magnetic field around itself, whether it be embedded in iron or lie in air. Armature inductors, therefore, create magnetic fluxes around themselves, and these fluxes will, in part, interfere with the main flux from the poles of the field magnet. The effect of these fluxes is:



FIGS. 1,411 and 1,412. Section of armature and field showing *distorting effect* of armature reaction on the field. When a coil is opposite a pole as in fig. 1,411, no current is flowing (assuming no self induction) and the field is undisturbed, but, as the inductors pass under a pole face as in fig. 1,412, current is induced in them, and lines of force are set up as indicated by the dotted lines. This distorts the main field so that the lines of force are crowded toward the forward part of the pole face as shown.

1. To distort the field, or
2. To weaken the field.

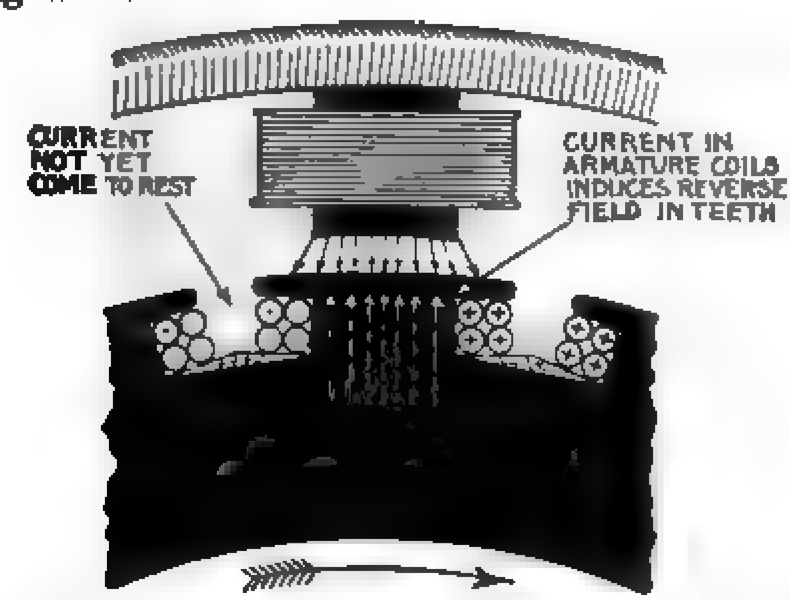
These disturbing fluxes form, in part, stray fluxes linked around the armature inductors tending to choke the armature current.

Ques. Explain how the field becomes distorted by armature reaction.

Ans. Considering a slotted armature and analyzing the electrical conditions as the inductors move past a pole piece, it *will be observed:* 1, when the coil is in the position shown in

[redacted]

ig. 1,411, the current will be zero, assuming no armature self-nduction, consequently for this position the armature coil has no disturbing effect upon the field set up by the field magnet; 2, when the inductors have moved under the pole face, as in ig. 1,412, currents will be induced in them, and they will tend to set up a magnetic field as indicated by the dotted lines, and n direction, by the arrow heads. The effect of this field will be o distort the main field, strengthening one side of the pole and weakening the other side.



'IG. 1,413.—Section of armature and field showing *weakening effect* of armature reaction in the field. Self-induction being present (as it almost always is), the current lags more or less behind the pressure, so that when the coil is in the position of zero induction, as shown, the current has not yet come to rest. Accordingly, lines of force (indicated by the dotted lines) are set up by the current flowing through the coils which are in opposition to the field, thus weakening the latter. The dots and crosses in inductor sections, have their usual significance in defining the direction of current, representing respectively the heads and tails of arrows.

Ques. Explain how the field becomes weakened by armature reaction.

Ans. In all armatures there is more or less inductance which causes the current to lag behind the pressure a corresponding amount. Accordingly, the current does not stop flowing at the same instant that the pressure becomes zero, therefore, when the coil is in the *position* of zero pressure, as in fig. 1,413,

the current is still flowing and sets up a magnetic field which opposes the main field as indicated by the dotted arrows, thus weakening the main field.

Ques. In what kind of armature is this effect especially pronounced?

Ans. In slotted armatures provided with coils of a large number of turns.

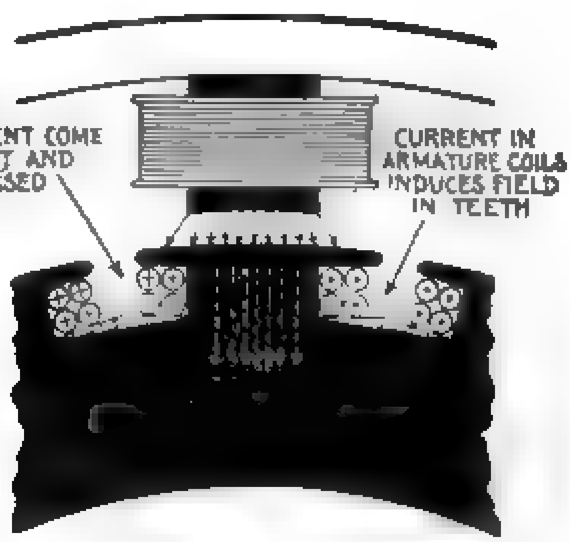


FIG. 1,414.—Section of armature and field showing *strengthening effect* of armature reaction when the current leads the pressure. If the circuit contain an excess of capacity the current will lead the pressure, so that when the coil is in the position of zero induction, as shown, the current will have come to rest and reversed. Accordingly, lines of force (indicated by the dotted lines) are set up by the current flowing through the coil and which are in the same direction as the lines of force of the field, thus strengthening the latter.

Ques. What would be the effect if the current lead the pressure?

Ans. It would tend to strengthen the field as shown in fig. 1,414.

The value of the armature ampere turns which tend to distort and to diminish or augment the effect of the ampere turns on the field magnet is sometimes calculated as follows:

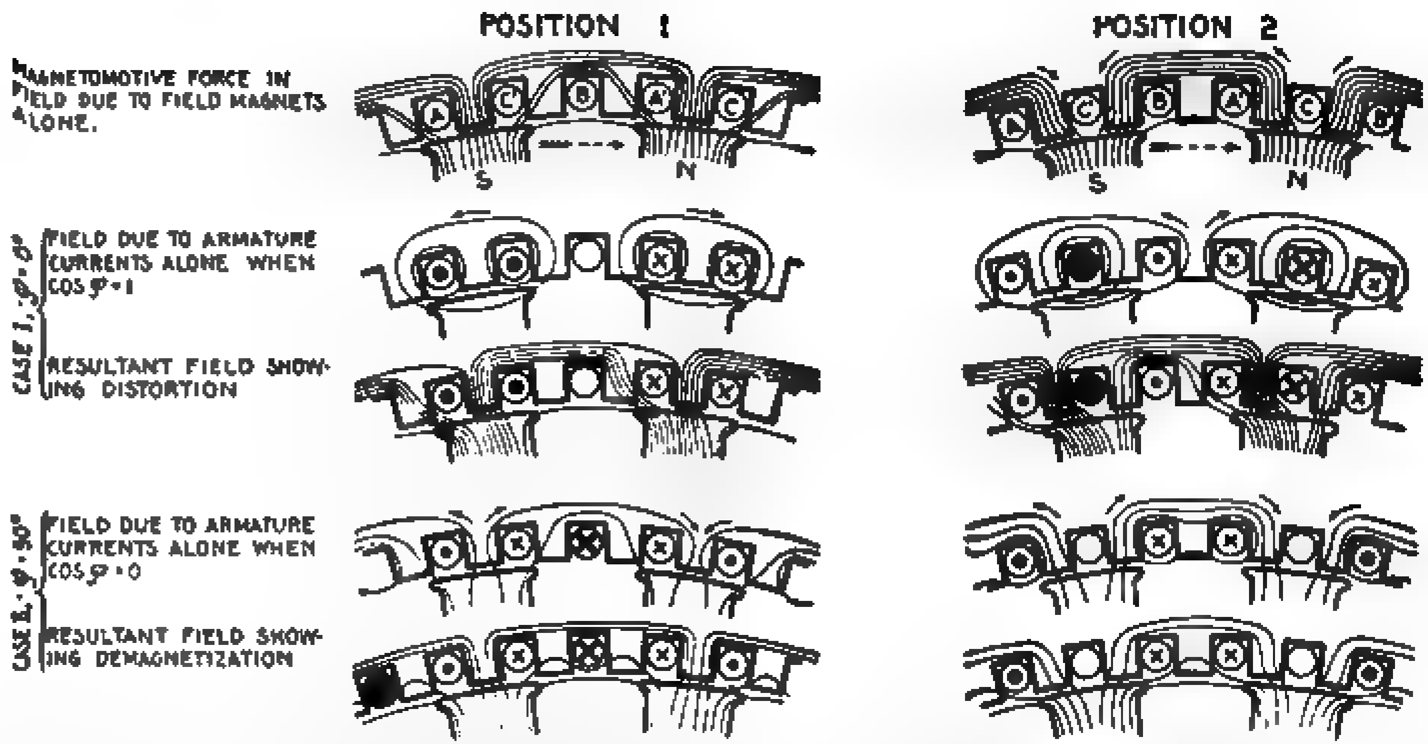
$$A = \frac{.707 \times I \times T \times P}{s}$$

in which
A = armature ampere turns;
I = current per phase;
T = turns per pole per phase;
P = number of phases;
s = product of the distribution and pitch factors of the winding.

This value of ampere turns, combined at the proper phase angle with the field ampere turns gives the value of the ampere turns available for producing useful flux.

FIG. 1,415.—Fort Wayne separately excited belt driven alternator, a form adapted for installation in small plants where low power factor is to be encountered. This condition exists in a line where power is supplied to induction motors, transformers or other inductive apparatus. The type here shown is built in sizes from 37½ kw. to 200 kw., 60 cycles, two or three phases and voltages of 240, 480, 600, 1,150 or 2,300 volts. They may be operated as single phase alternators by using two of the phases and may then be rated at 70 per cent. of the polyphase rating. The field is excited by direct current at a pressure of 125 volts. These alternators may be used as synchronous motors and for this duty are fitted with amortisseur winding in the pole faces which does not interfere with their use as alternators.

Single Phase Reactions.—Unlike three phase currents, a single phase current in an alternator armature produces a periodic disturbance of the flux through the machine. In the magnet system this disturbance is of twice the normal frequency, while in the armature core it is the



FIGS. 1,416 to 1,425.—Diagrams illustrating superposition of fields. In the figures magnetic curves representing the effect of the armature currents in several different cases are superposed upon the magnetic curves assumed to be due to the field magnet. The uppermost line shows the primary field due to the exciting coils on the magnet poles. They are shown passing into the armature teeth in two principal positions, where the middle of a pole is: 1, opposite a tooth, and 2, opposite a slot. In the second line is shown the field due to the armature currents assuming no lag, and that the magnets are not excited. If there be no lag, the places of strongest current will be opposite the poles. As shown in the right hand figure when the current in one phase C, is at its maximum, those in the other phases A and B will be of half strength. In the left hand figure when the current in one phase B, is at its zero value, those in the other phases will be of equal value, or 87 per cent. of the maximum. In the third line is shown the effect of superposing these fields due to the current upon those due to the magnets as depicted in the first line. Inspection of this resultant field shows how the armature current distorts the field without altering the total number of lines per pole. In the fourth and fifth lines are shown the effects of a lagging current. A lag of 90° is assumed; and in that case the maximum current occurs in any inductor one quarter period after the pole has passed, or at a distance of half a pole pitch behind the middle point of the pole, as in the fourth line. When these armature fields are superposed on those of the magnets in the first line the resultant fields are those depicted in the fifth line. On inspection it will be seen that in this case there is no distortion, but a diminution of the flux from each pole, as the lines due to the armature currents, tending to pass through the pole cores in the sense opposite to those of the primary magnetism, must be deducted from the total. The twelve lines per pole are correspondingly reduced to eight; and, of these eight, four go astray constituting a leakage field. This illustrates the effect of a lagging current in demagnetizing the field magnets and in increasing the dispersion.

same as the normal frequency. In both cases the eddy currents which are set up, produce a marked increase in the load losses, and thus tend to give the machine a higher temperature rise on single phase loading.

Designers continue to be singularly heedless of these single phase reactions, resulting in many cases of unsatisfactory single phase alternators. Single phase reactions distort the wave form of the machine.

Three Phase Reactions.—The action of the three phase currents in an alternator is to produce a resultant field which is practically uniform, and which revolves in synchronism with the field system. The resultant three phase reaction, because of its uniformity, produces no

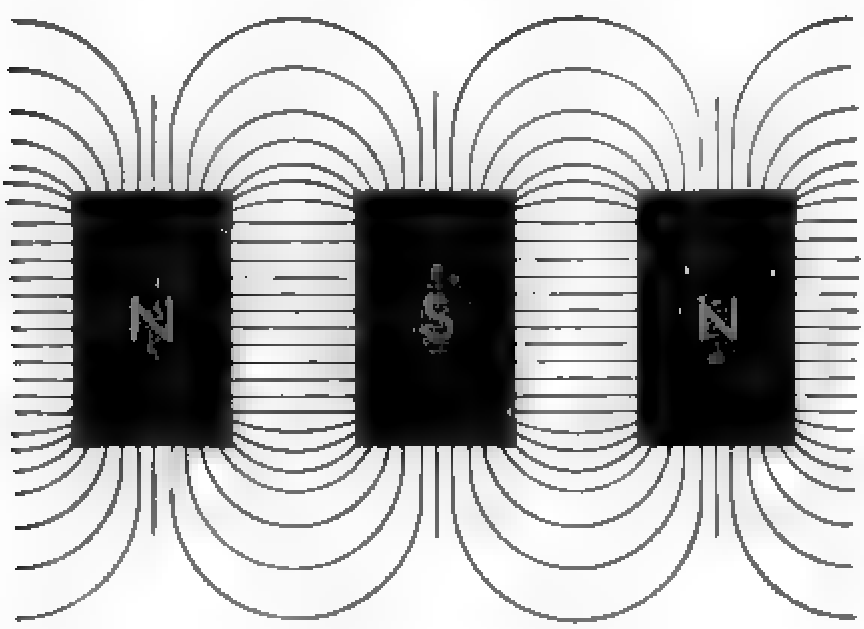


FIG. 1,426.—Diagram showing lateral field between adjacent poles.

great increase in the load losses of the machine, the small additional losses which are present being due to windings not being placed actually in space at 120°, and to the local leakage in the teeth.

Magnetic Leakage.—In the design of alternators the drop of voltage on an inductive load is mainly dependent upon the magnetic leakages, primary and secondary. They increase with the load, and, what is of more importance, they increase with the fall of the power factor of the circuit on which they may be working. This is one reason why certain types of alternator,

though satisfactory on a lighting circuit, have proved themselves unsatisfactory when applied to a load consisting chiefly of motors.

The designer must know the various causes which contribute to leakage and make proper allowance.

In general, to keep the leakage small, the pole cores should be short, and of minimum surface, the pole shoes should not have too wide a span nor be too thick, nor present needless

FIGS. 1,427 and 1,428.—Diagram showing respectively the character of stray field between adjacent straight poles, and between adjacent poles with shoes. Across the slightly V-shaped spaces the stray field passes in lines that, save near the outer part, are nearly straight. Quite straight they would not be, even were the sides parallel, because the difference of magnetic pressure increases from the roots towards the pole ends. At the roots, where the cores are attached to the yoke, the magnetic pressure difference is almost zero. It would be exactly zero if there were not a perceptible reluctance offered by the joints and by the metal of the yoke. The reluctance of the joint causes a few of the lines to take paths through the air by a leakage which adds to the useful flux. At the tops of the cores there is a difference of magnetic pressure equal to the sum of the ampere-turns on the two cores, tending to drive magnetic lines across. This difference of magnetic pressure increases regularly all the way up the cores from root to top, hence, the average value may be taken as equal to the ampere turns on one core. The stay field, therefore, will steadily increase in density from the bottom upwards. In addition to this stray field between the pole cores there is also a stray field between the projecting tips or edges of the pole shoes, as shown in fig. 1,428. In some machines the dispersion due to the pole shoes is greater than that between the flanks of the cores.

corners, and the axial length of the pole face and of the armature core should not be too great in proportion to the diameter of the working face.

To keep the increase of leakage between no load and full load from undue magnitude, it is required that armature reactions

shall be relatively small, that the peripheral density of the a ture current (ampere-conductors per inch) be not too great, that the pole cores be not too highly saturated when excitec no load.

FIG. 1,429 —Lincoln revolving field alternator. The frame has openings for ventilation, the fanning action of the pole pieces causing a current of air to pass not only over the end of the windings, as is usual with other designs, but also through ventilating slots in the windings themselves. The armature core laminations are annealed after punching and before assembling to guard against the crystalizing effect of the punching. The armature coils are form wound and insulated before being placed in the slot. There is also slot insulation which is put in the slot previous to inserting the coil. When the winding is completed, it is tested with a pressure of 4 to 10 times the normal voltage of the machine. The bearings are self-aligning. The machine is normally designed to operate at a power factor of approximately 70 per cent., which means that at that power factor, the armature and fields at full load will heat equally If it have a higher power factor than 70 per cent. it means that the field windings will run considerably cooler than the armature windings with full load. If the power factor be lower than this, it will mean that the field windings will run hotter than the armature on full load; however, the machine is designed so that harmful heating does not occur on full load with greater power factor than 40 per cent.

The general character of the stray field between adjacent poles shown in figs. 1,427 and 1,428 for straight poles and those ving shoes

Field Excitation of Alternators.—The fields of alternators require a separate source of direct current for their excitation, and this current should be preferably automatically controlled. In the case of alternators that are not self exciting, the dynamo which generates the field current is called the *exciter*.

The excitation of an alternator at its rated overload and .8 power factor would not, in some cases, if controlled by hand, exceed 125 volts, although, in order to make its armature voltage respond quickly to changes in the load and speed, the excitation of its fields may at times be momentarily varied by an automatic regulator between the limits of 70 and 140 volts.

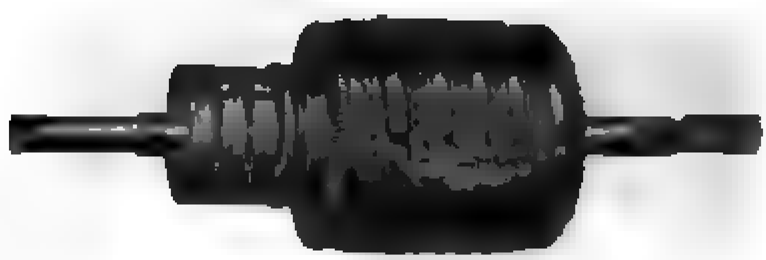


FIG. 1,430.—Western Electric armature for self-excited alternator. The main winding is placed at the bottom of the slots, each coil being surrounded by an armour of horn fibre. The exciter winding occupies a very small portion of the slot, being placed on top of the main winding, and connected to the commutator immediately in front of the core and between core and collector rings as shown.

The exciter should, in turn, respond at once to this demand upon its armature, and experience has shown that to do this its shunt fields must have sufficient margin at full load to deliver momentarily a range from 25 to 160 volts at its armature terminals.

It is obvious from the above that an exciter suitable for use with an automatic regulator must commutate successfully over a wide range in voltage, and, if properly designed, have liberal margins in its shunt fields and magnetic circuits.

Alternator fields designed for and operated at unity power factor have often proved unsatisfactory when the machines were called upon to deliver their rated kva. at .8 power factor or lower. This is due to the increased field current required at the latter condition and results, first, in the overheating of the fields and, second, in the necessity of raising the direct current exciting voltage above 125 volts, which often requires the purchase of new exciters.

Ques. What is a self-excited alternator?

Ans. One whose armature has, in addition to the main winding, another winding connected to a commutator for furnishing direct field exciting current, as shown in fig. 1,430.

FIG. 1,431.—Frame, bed plate and armature winding for Westinghouse bracket bearing polyphase alternator.

Ques. How is a direct connected exciter arranged?

Ans. The exciter armature is mounted on the shaft of the alternator close to the spider hub, or in some cases at a distance sufficient to permit a pedestal and bearing to be mounted between the exciter and hub. In other designs the exciter is placed between the bearing and hub.

Figs. 1,432 and 1,433 are examples of direct connected exciter alternators, in fig. 1,432 the exciter being placed between the field hub and bearing, and in fig. 1,433, beyond the bearing.

Ques. What is the advantage of a direct connected exciter?

Ans. Economy of space.

This is apparent by comparing figs. 1,432 and 1,433 with fig. 1,434 which shows a belted exciter.

FIG. 1,432.—General Electric alternator with direct connected exciter mounted on shaft between field hub and bearing. In the smaller sizes, the magnet frame is bolted to the bearing bracket, but in the larger sizes special construction is used depending upon the conditions to be met. The exciters are capable of furnishing the desired excitation for low power factors.

Ques. What is the disadvantage of a direct connected exciter?

Ans. It must run at the same speed as the alternator, which *slower than desirable,* hence the exciter must be larger for

given output than the gear driven type, because the latter can be run at high speed and accordingly be made proportionally smaller.

Ques. What form of gear is generally used on gear driven exciters?

Ans. Belt gear.

FIG. 1,433.—Fort Wayne alternator with direct connected exciter mounted on the field shaft at such distance as to permit a pedestal and bearing to be mounted between the exciter and revolving field. In the view, the bearing is hidden by the exciter, only the foot of the pedestal being visible.

Ques. What are the advantages of gear driven exciters?

Ans. Being geared to run at high speed, they are smaller and therefore less *costly than* direct connected exciters. In large

plants containing a number of alternators one exciter may be used having sufficient capacity to excite all the alternators, and which can be located at any convenient place.

Ques. What is the disadvantage of gear driven exciters?

Ans. The space occupied by the gear.

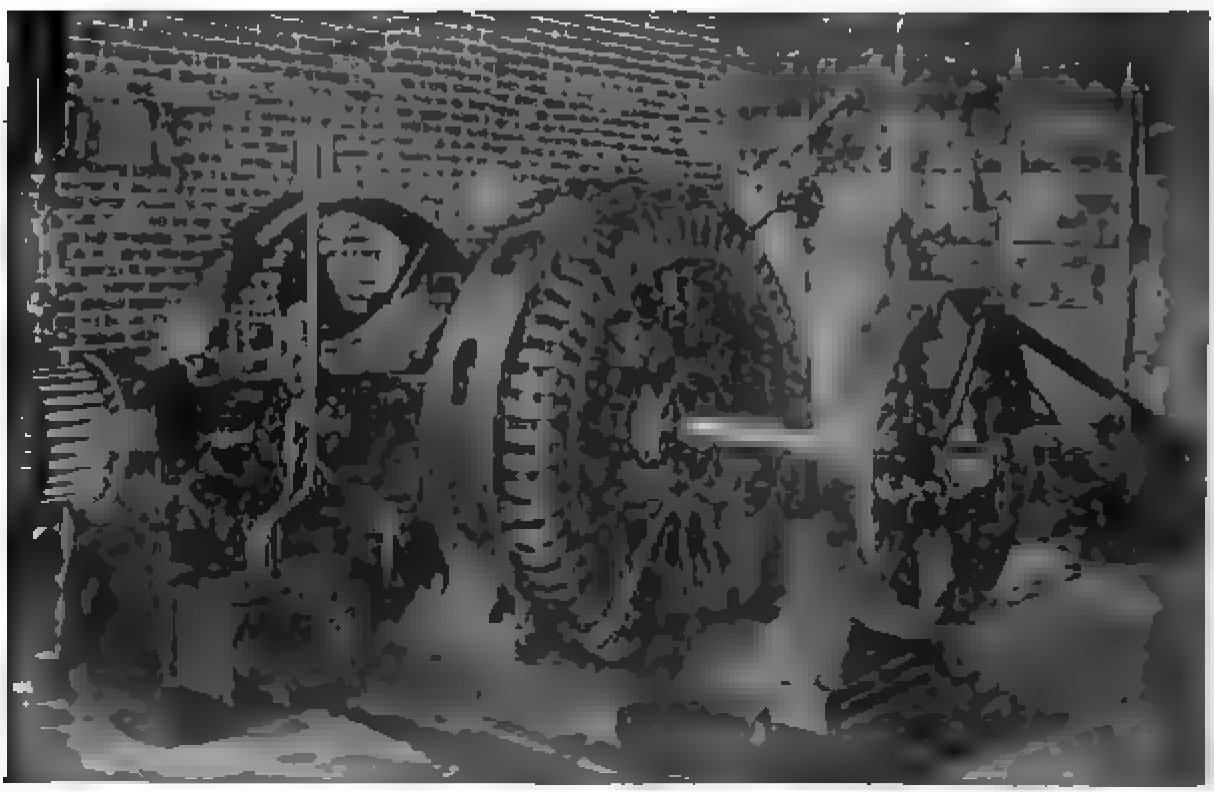


FIG. 1,434.—Diagram showing a Westinghouse 50 kva., 2,400 volt, three phase, 60 cycle revolving field separately excited alternator direct connected to a steam engine. The exciter is belted to the alternator shaft the driving pulley being located outside the main bearing. The small pulley on the exciter gives an indication of its high speed as compared with that of the alternator.

In the case of a chain drive very little space is required, but for belts, the drive generally used, there must be considerable distance between centers for satisfactory transmission.

Slow Speed Alternators.—By slow speed is here understood relatively slow speed, such as the usual speeds of reciprocating engines. A slow speed alternator is one designed to run at a *speed slow enough* that it may be direct connected to an engine.

Such alternators are of the revolving field type and a little consideration will show that they must have a multiplicity of field magnets to attain the required frequency.

In order that there be room for the magnets, the machine evidently must be of large size, especially for high frequency.

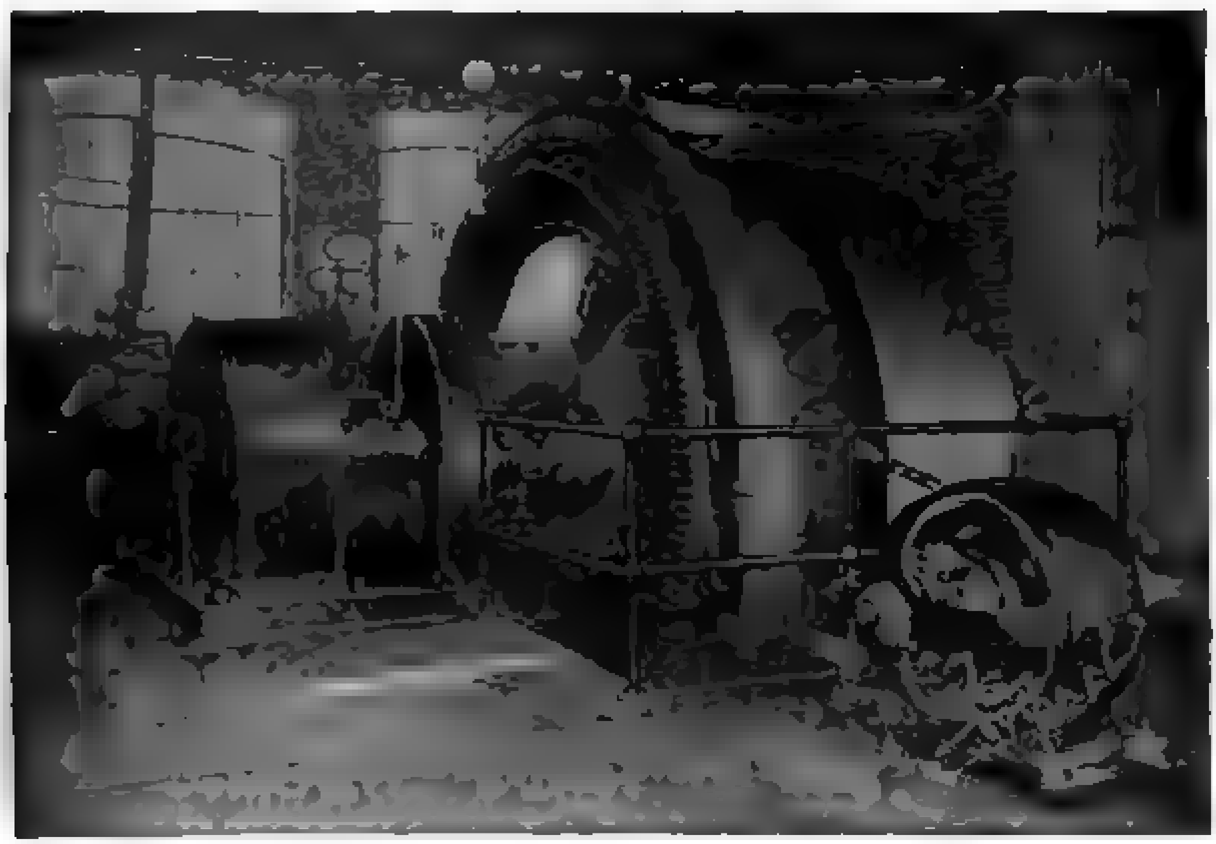


FIG. 1,435.—Crocker-Wheeler 350 kva., slow speed alternator direct connected to a Corliss engine. In front is seen a belted exciter driven from a pulley on the main shaft between the alternator and the large band wheel. The latter serves to give the additional fly wheel effect needed for close speed regulation.

EXAMPLE.—How many field magnets are required on a two phase alternator direct connected to an engine running 240 revolutions per minute, for a frequency of 60?

An engine running 240 revolutions *per minute* will turn

$$240 \div 60 = 4 \text{ revolutions } \textit{per second.}$$

A frequency of 60 requires

$$60 \div 4 = 15 \text{ cycles per phase per revolution, or}$$

$$15 \times 2 = 30 \text{ poles per phase.}$$

Hence for a two phase alternator the total number of poles required is

$$30 \times 2 = 60.$$

It is thus seen that a considerable length of spider rim is required to attach the numerous poles, the exact size depending upon their dimensions and clearance.

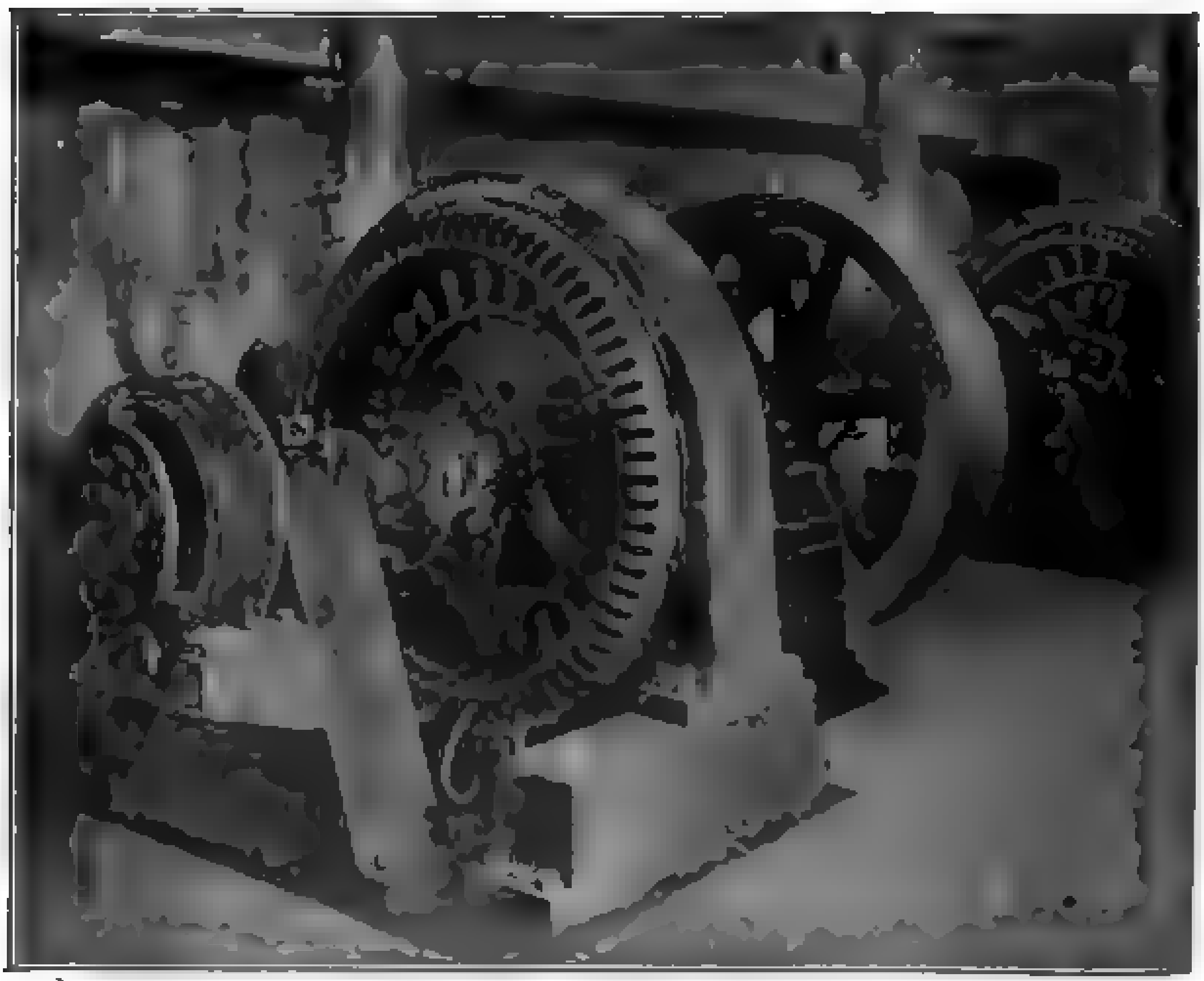
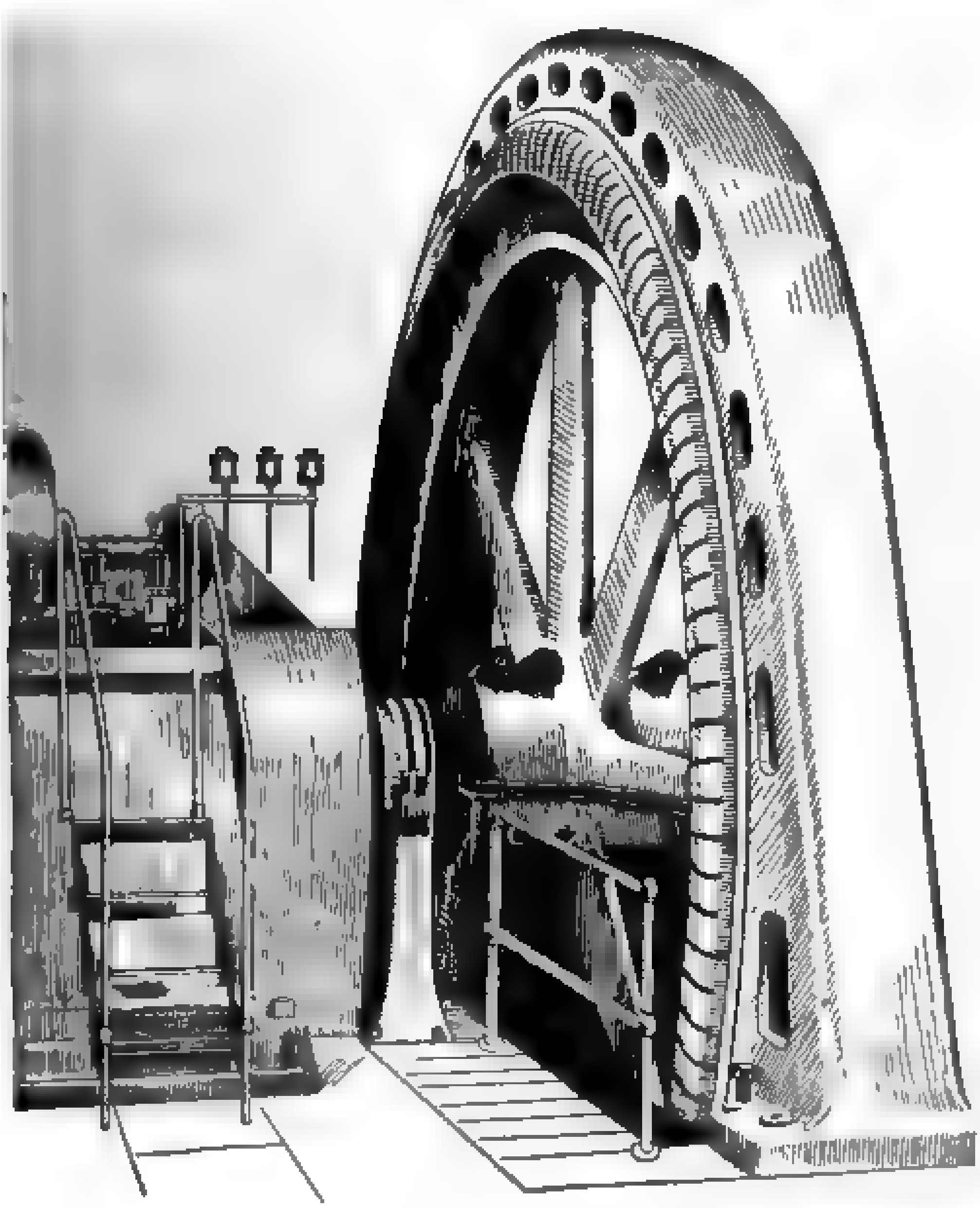


FIG. 1,436.—Three Crocker-Wheeler 75 kva., slow speed alternators direct connected to high speed engines. The alternator is styled slow speed although connected to a high speed engine, because what is considered high engine speed is slow speed for alternator operation. The alternators have direct connected exciters which are plainly seen in the illustration placed on an extension of bearing pedestal. Direct connected exciters on units of this kind do not, as a rule, assume too bulky proportions, because of the high engine speed.

Fly Wheel Alternators.—The diameter of the revolving fields on direct connected alternators of very large sizes becomes so great that considerable fly wheel effect is obtained, although *the revolutions* be low. By giving liberal thickness to the rim

the spider, the rotor then answers the purpose of a fly wheel, nce no separate fly wheel is required. In fact, the revolving ment resembles very closely an ordinary fly wheel with mag- ts mounted on its rim, as illustrated in fig. 1,437.



1,437.—General Electric 48 pole 750 kw., three phase fly wheel type alternator. It runs at a speed of 150 revolutions per minute, giving a frequency of 60 cycles per second and a full load pressure of 2,300 volts. The slip rings and leads to the field winding are clearly shown in the figure. The field magnets are mounted directly on the rim of the spider, which resembles very closely a fly wheel, and which in fact it is—hence the name "fly wheel alternator."

High Speed Alternators.—Since alternators may be run at speeds far in excess of desirable engine speeds, it must be evident that both size and cost may be reduced by designing them for high speed operation.

Since the desired velocity ratio or multiplication of speed is so easily obtained by belt drive, that form of transmission is generally used for high speed alternators, the chief objection

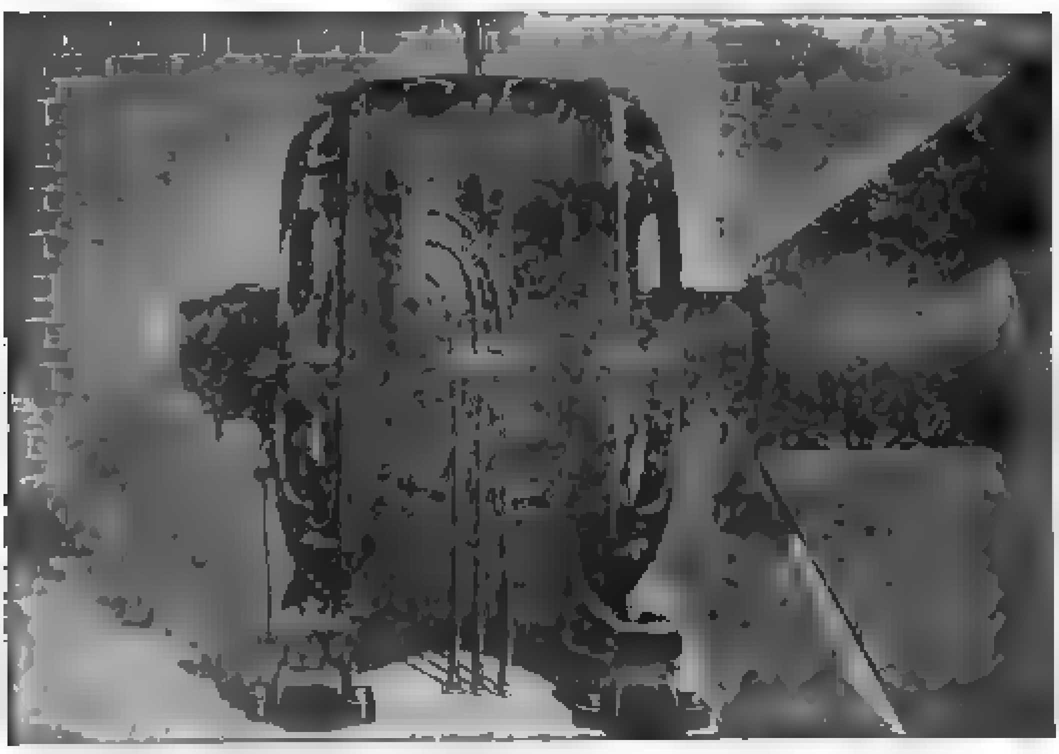


Fig. 1,438. Allis-Chalmers high speed belted type alternator. The small pulley at the right and the angle of the belt suggest the high speed at which such alternators are run, a 50 kva. machine turning 1,200 revolutions per minute.

being the space required. Accordingly where economy of space is not of prime importance, a high speed alternator is usually installed, except in the large sizes where the conditions naturally suggest a direct connected unit.

An example of high speed alternator is shown in fig. 1,438. Machines of this class run at speeds of 1,200 to 1,800 or more, according to size.

No one would think of connecting an alternator running at any such speed direct to an engine, the necessary speed reduction proper for *engine operation* being easily obtained by means of a belt drive.

No one would think of connecting an alternator running at such speeds direct to an engine, the necessary speed reduction proper for engine operation being easily obtained by means of a belt drive.

Water Wheel Alternators.—In order to meet most successfully the requirements of the modern hydro-electric plant, the alternators must combine those characteristics which result in high electrical efficiency with a mechanical strength of the moving elements which will insure uninterrupted service, and

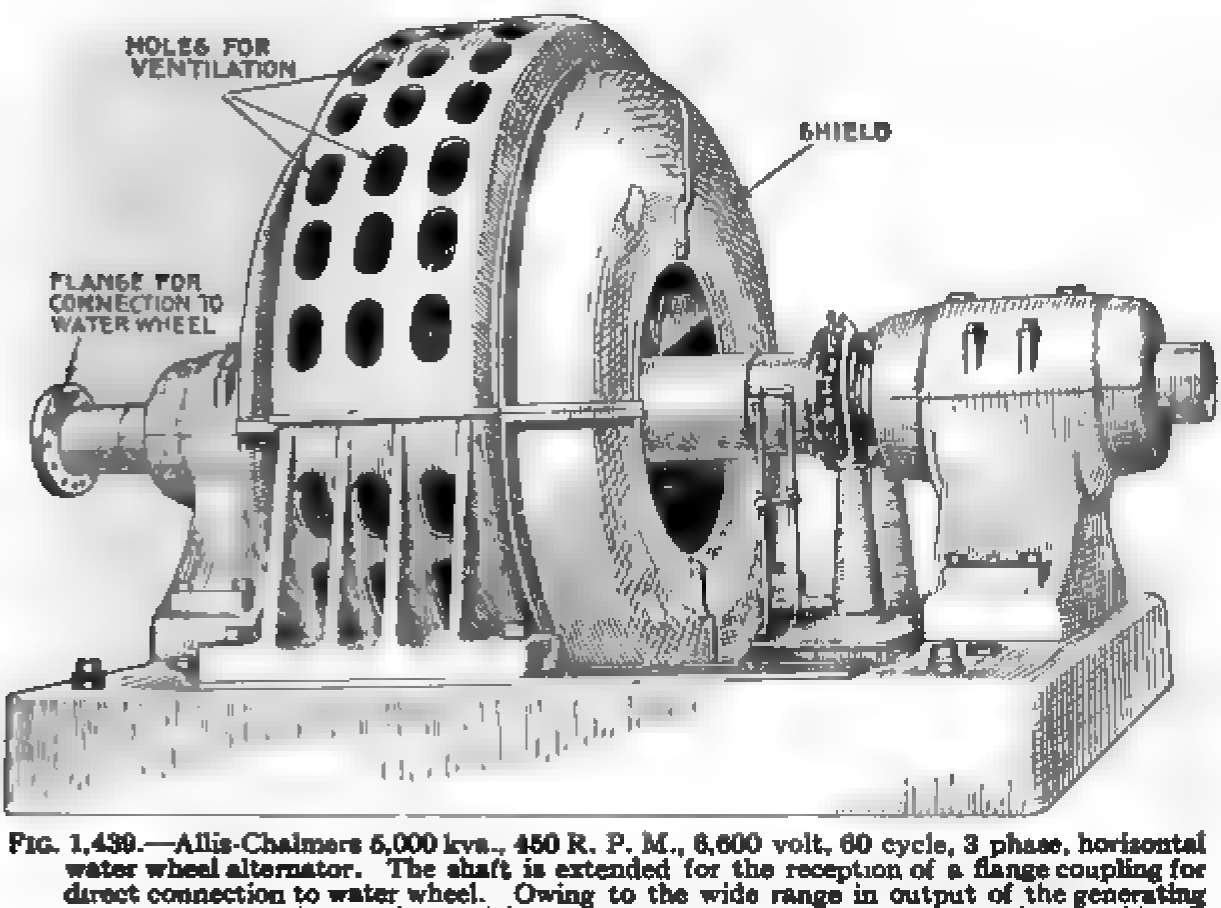


FIG. 1,439.—Allis-Chalmers 5,000 kva., 450 R. P. M., 6,600 volt, 60 cycle, 3 phase, horizontal water wheel alternator. The shaft is extended for the reception of a flange coupling for direct connection to water wheel. Owing to the wide range in output of the generating units and also in the speed at which they must operate to suit varying conditions of head, types of wheels used, and other features pertaining to water power developments, it has been necessary to design a very complete line of machines for this work. The bearings are of the ring oiling type with large oil reservoirs.

an ample factor of safety when operating at the relatively high speeds often used with this class of machine

When selecting an alternator for water wheel operation a careful analysis of the details of construction should be made in

order to determine the relative values which have been assigned by the designers to the properties of the various materials used. Such analysis will permit the selection of a type of machine best adapted to the intended service and which possesses the required characteristics of safety, durability and efficiency.

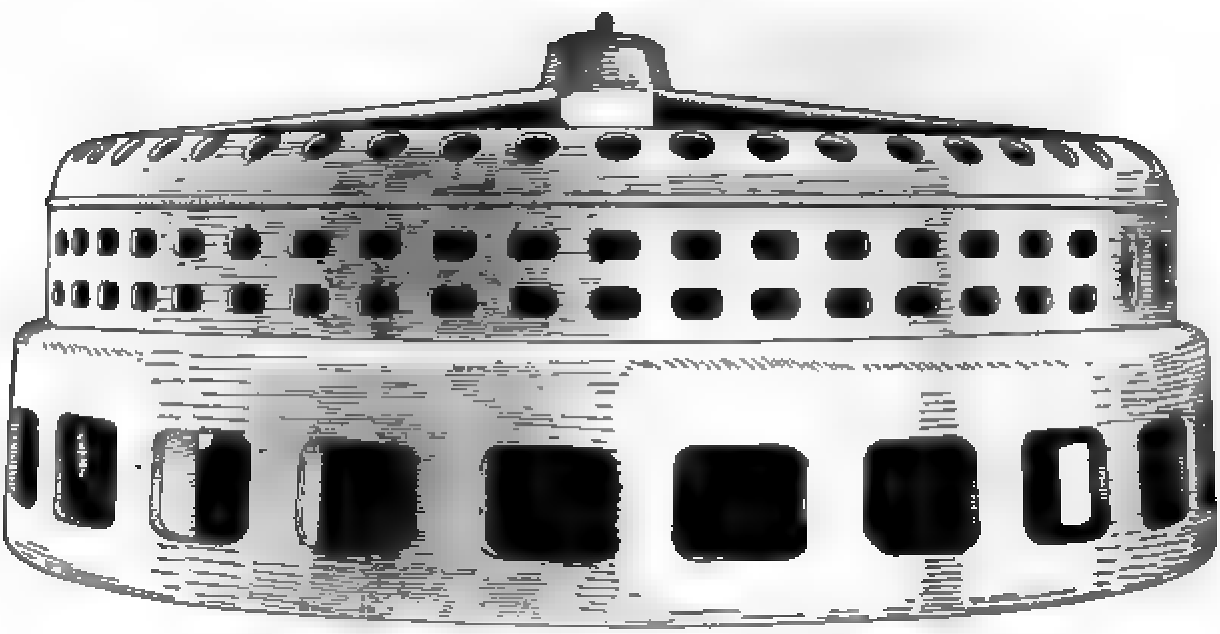


FIG. 1,440.—Stator of 500 k.w. Allis-Chalmers alternator for direct connection to vertical shaft hydraulic turbine.

The large use of electric power transmitted by means of high pressure alternating current has led to the development of a large number of water powers and created a corresponding demand for alternators suitable for direct connection to water wheels.

Ques. Name two forms of water wheel alternator.

Ans. Horizontal and vertical.

Examples of horizontal and vertical forms of water wheel alternator are shown in figs. 1,439 and 1,440.

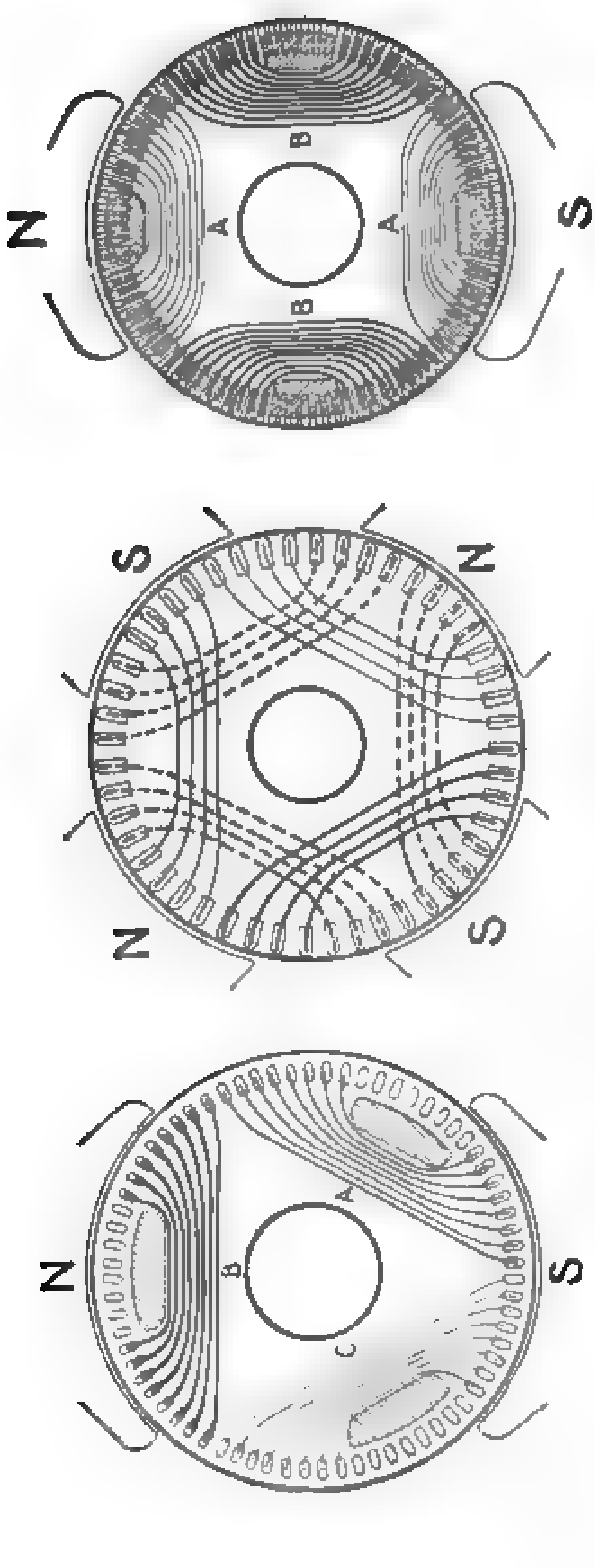
Ques. How should the rotor be designed?

Ans. It should be of very substantial construction.

Ques. **Why?**

Ans. Because water wheel alternators are frequently required to operate safely at speeds considerably in excess of normal.

FIG. 1,441.—Allis-Chalmers revolving field for water wheel alternator. In this type of alternator it is essential that the rotating part be designed to have a liberal factor of safety not only at the ordinary operating speed, but also at speeds much in excess of normal. Frequently machines are required to operate safely at a speed 50 to 75 per cent. in excess of normal, so that there may be no danger in case the water wheel races. In most machines the field spider is of steel cast in a single piece for the smaller alternators and in two or more parts for the larger sizes. For alternators running at high peripheral speed, the rim is built up of steel laminations supported by a cast steel spider; the latter serves merely to rotate the rim, which is in itself able to withstand all stresses due to the high speed. The field poles are laminated, being built up of steel punchings held between malleable iron or bronze end plates, the latter being used on high speed machines. With but very few exceptions the poles are attached by dovetail projections that fit into corresponding slots. Steel tapered keys are driven in alongside the dovetails, and the pole pieces cannot become loose. All field coils, except on a few of the smallest machines, are of edgewise wound copper strip. This style of coil is essential for revolving field alternators where the pressure on the insulation, due to centrifugal force, is so great that cotton insulation on round wire will not stand. Current is led into the rings by means of carbon brushes, the number of brushes being such that the current density at the rubbing contact is kept within conservative limits. At least two brushes per ring are always provided so that one can be removed for inspection without interrupting the exciting current. In large machines the brush holder studs are mounted on a stand supported from the base; in small alternators they are *usually fastened* to the cap of one of the bearing pedestals.



FIGS. 1,442 to 1,444.—Diagram of turbine alternator windings for revolving armature. Fig. 1,442 illustrates a two pole design in which all overlapping is avoided. It has 72 slots of which only 48 are filled, giving 8 slots per phase. The projecting claws from the brass end shield which hold the coils in position are shown in section. Fig. 1,443 shows a four pole design having 48 slots or 4 slots per phase per pole, the coils being made up of 8 inductors per slot taped together, the end bends forming two ranges. Fig 1,444 shows a two pole design for a two phase armature with 18 slots per pole per phase. The core discs are spaced out as for 108 slots, but of these, 4 lots of 7 each are not stamped out, and 8 of those stamped are left empty, so that there are 72 slots filled.

Ques. What special provision is made for cooling the bearings?

Ans. They are in some cases water cooled.

Turbine Driven Alternators.—Although the principle of operation of the steam turbine and that of the reciprocating engine are decidedly unlike, the principle of operation of the high speed turbine driven alternator does not differ from that of generators designed for being driven by other types of engine or by water wheels. There are, therefore, with the turbine driven alternator no new ideas for

the operator who is familiar with the older forms to acquire.

It must be obvious that the proportions of such extra high speed machines must be very different from those permissible in generators of much slower speeds.

Ques. How does a turbine rotor differ from the ordinary construction?

Ans. It is made very small in diameter and unusually long.

Ques. Why?

Ans. To reduce vibration and centrifugal stresses

Ques. What are the two classes of turbine driven alternators?

Ans. They are classed as vertical or horizontal.

Ques. How do they compare?

Ans. The vertical type requires less floor space than the horizontal design, and while a step bearing is necessary to carry the weight of the moving element, there is very little friction in the main bearings.

The horizontal machine, while it occupies more space, does not require a step bearing.

Ques. Describe a step bearing.

Ans. It consists of two cylindrical cast iron plates bearing upon each other and having a central recess between them into which lubricating oil is forced under considerable pressure by a steam or electrically driven pump, the oil passing up from beneath.

Ques. What auxiliary is generally used in connection with a step bearing?

Ans. A weighted accumulator is sometimes installed in

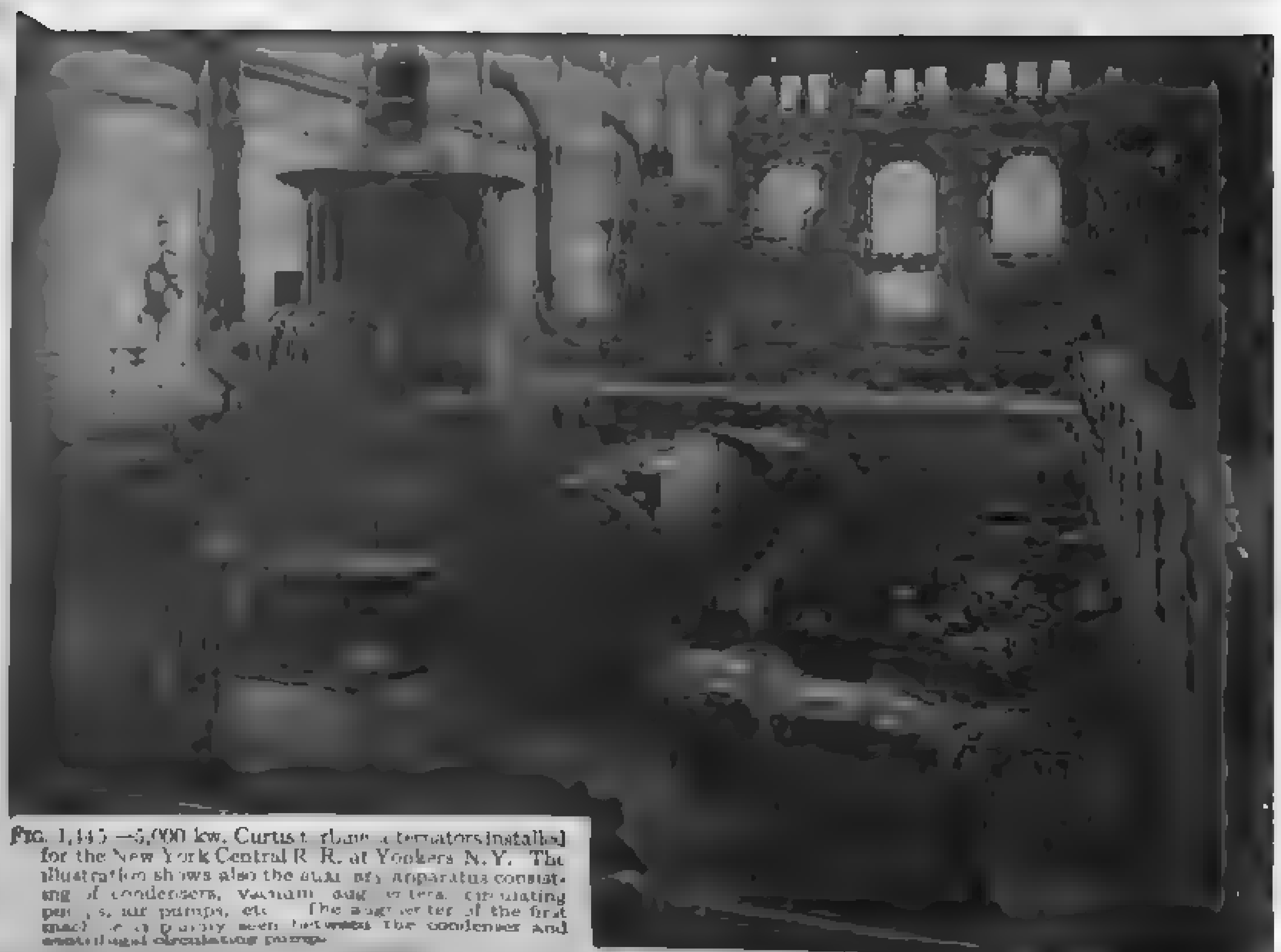


FIG. 1,445.—5,000 kw. Curtis turbine alternators installed for the New York Central R. R. at Yonkers N. Y. The illustration shows also the auxiliary apparatus consisting of condensers, vacuum [illegible] filters, circulating pumps, air pumps, etc. The [illegible] of the first machine is plainly seen between the condenser and centrifugal circulating pump.

[redacted]

nnection with the oil pipe as a convenient device for govern-
g the step bearing pumps, and also as a safety device in case
e pumps fail.

Alternators of Exceptional Character.—There are a few types of alternator less frequently encountered than those already described. The essentials of such machines are here briefly given.

Asynchronous Alternators.—In these machines, the rotating magnet, which, with definite poles, is replaced by a rotor having closed circuits. In general construction, they are similar to asynchronous induction motors having short circuited rotors; for these alternators, when operating as motors, run at a speed slightly below synchronism and act as generators when the speed is increased above that of synchronism. Machines of this class are not self-exciting, but require an alternating or polyphase current previously supplied to the mains to which the stationary armature is connected.

Asynchronous alternators may be advantageously used in central stations that may be required to sustain a very sudden increase of load. In such cases, one or more asynchronous machines might be kept in operation as a non-loaded motor at a speed just below synchronism until its output as a generator is required; when by merely increasing the speed of the engine it will be made to act as a generator, thus avoiding the delays usually occurring before switching in a new alternator.

Image Current Alternators.—When the generated frequency of alternators excited by low frequency currents is either the sum or the difference of the excitation and rotation frequencies, any load current flowing through the armature of the machine is exactly reproduced in its field circuit. These reproduced currents are characteristic of all types of asynchronous machines, and are called "image currents," as they are actually the reflection from the load currents delivered by the armature circuit.

As the exciter of a machine of this type carries "*image currents*" proportional to the generated currents, its size must be proportional to the capacity of the machine multiplied by the ratio of the excitation and generated frequencies; therefore, in the commercial machines, the excitation frequency is reduced to the minimum value possible; from two to five cycles per second being suitable for convenient employment.

These machines as heretofore constructed are not self-exciting, but as the principle of image current enables the construction of self-exciting alternators, it will be of advantage to have a general understanding of the separately excited machine under different conditions of excitation.

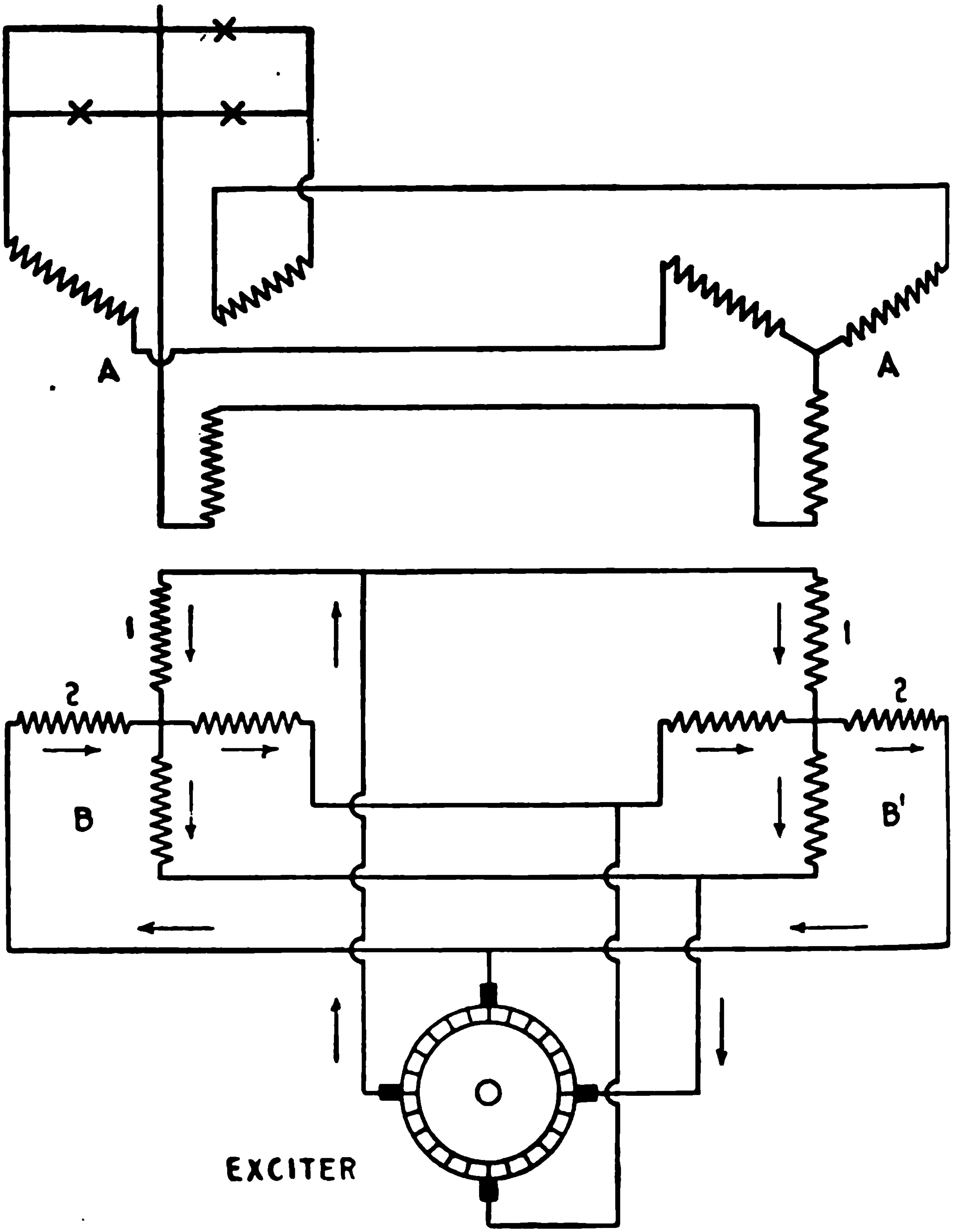


FIG. 1446.—Diagram of constant pressure image current alternator connections. The image or reproduced currents are characteristic of all types of asynchronous machines, and are called image currents because they are actually the reflection from the load currents delivered by the armature circuit. The principle of operation is explained in the accompanying text.

When the generated frequency of the machine is equal to the difference of the excitation and rotation frequencies, the magnetization of the machine is higher under a non-inductive load than under no load. This is principally due to the ohmic resistance of the field circuit, which prevents the image current from entirely neutralizing the magnetomotive force of the armature current. In other words, the result of the magnetomotive force of the armature and image currents not only tends to increase the no load magnetization of the machine at non-inductive load, but depresses the original magnetization at inductive load, so that the terminal voltage of the machine increases with non-inductive load, and decreases with inductive load.

Again, the generated frequency is equal to the sum of the excitation and rotation frequencies, the resistance of the field circuit reacts positively; that is, it tends to decrease the magnetization, and consequently the terminal voltage of the machine at both inductive and non-inductive loads.

In the constant pressure machine, the two effects are combined and opposed to one another.

The connections of two alternators with diphase excitation are shown by fig. 1,446.

Extra High Frequency Alternators.—Alternators generating currents having a frequency up to 10,000 or 15,000 cycles per second have been proposed several times for special purposes, such as high frequency experiments, etc. In 1902 Nikola Tesla proposed some forms of alternators having a large number of small poles, which would generate currents up to a frequency of 15,000 cycles per second.

Later, the Westinghouse Company constructed an experimental machine of the inductor alternator type for generating currents having a frequency of 10,000 cycles per second. This machine was designed by Samms. It had 200 polar projections with a pole pitch of only 0.25 inch, and a peripheral speed of 25,000 feet per minute. The armature core was built up of steel ribbon 2 inches wide and 3 mils thick. The armature had 400 slots with one wire per slot, and a bore of about 25 inches. The air gap was only 0.03125 inch. On constant excitation the voltage dropped from 150 volts at no-load to 123 volts with an output of 8 amperes.

Self-Exciting Image Current Alternators.—The type of machine described in the preceding paragraph can be made self-exciting by connecting each pair of brushes, which collect the current from the armature, with a field coil so located that the flux it produces will be displaced by a pre-determined angle depending on the number of phases required, as shown by fig. 1,447. The direction of the residual magnetism of the machine is shown by the arrows A, A.

When the armature is rotated, a pressure will be generated between the brushes 2 and 4, and a current will flow from C through the coils XX to B, producing a flux through the armature at right angles to the residual magnetism and establishing a resultant magnetic field between D, B, and D, C. This field will generate a pressure between the brushes 1 and 3, and a current will flow D through XX to E in such a direction that it will at first be opposed to the residual magnetism, and afterward

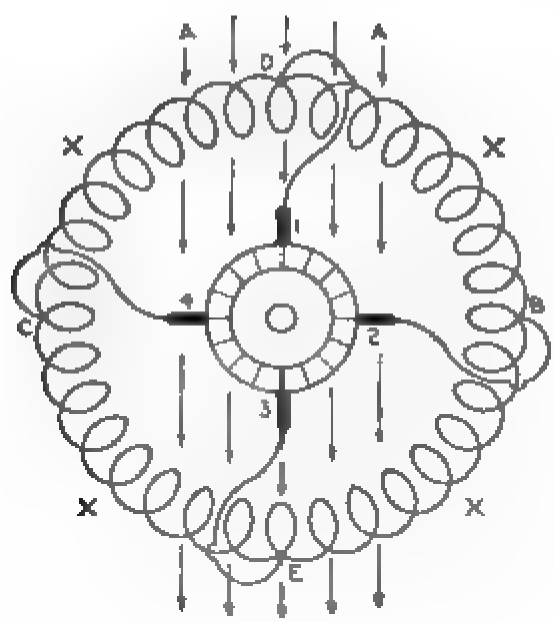


FIG. 1,447.—Diagram of connections of self-exciting image current alternator.

reverse the direction of the latter. At the moment the residual magnetism becomes zero, the only magnetism left in the machine will be due to the currents from the brushes 2 and 4, and their field combining with the vertical reversed field will produce a resultant polar line between B and E. As these operations are cyclic, they will recur at periodic intervals, and the phenomena will become continuous. The negative field thus set up in the air gap of the machine will cut the conductors of the stator and will be cut by the conductors of the rotor in such a manner that the electromotive forces generated between the brushes of the armature will be equal and opposite to those between the terminals of the stator.

CHAPTER L

CONSTRUCTION OF ALTERNATORS

The construction of alternators follows much the same lines as dynamos, especially in the case of machines of the revolving armature type. Usually, however, more poles are provided than on direct current machines, in order to obtain the required frequency without being driven at excessive speed.

The essential parts of an alternator are:

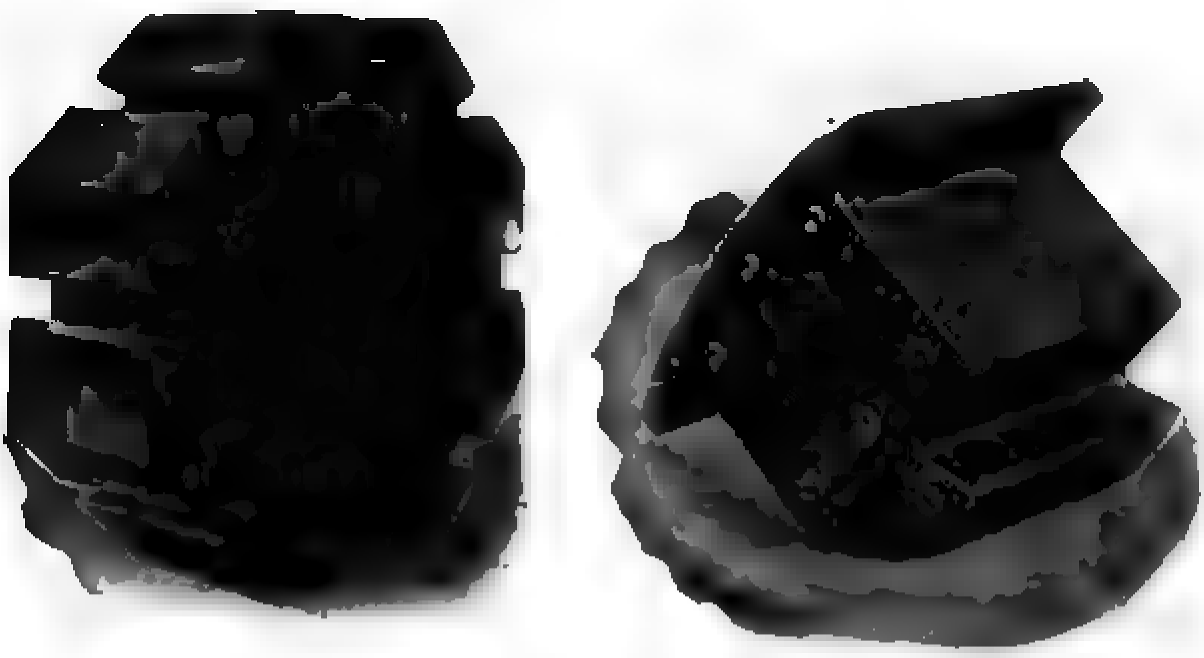
1. Field magnets;
2. Armature;
3. Collector rings;

and in actual construction, in order that these necessary parts may be retained in proper co-relation, and the machine operate properly there must also be included:

4. Frame;
5. Bed plate;
6. Pulley.

Field Magnets.—The early forms of alternator were built with permanently magnetized steel magnets, but these were later discarded for electro-magnets.

Alternators are built with three kinds of electro-magnets, classed according to the manner in which they are excited, the machines being known as



FIGS. 1,448 and 1,449.—Westinghouse laminated hub and laminated pole piece for revolving field having squirrel cage winding. Thin steel is used for the laminations of both hub and pole piece; these are assembled and firmly riveted together under hydraulic pressure. The laminations are of the same thickness in both hub and spider.

FIGS. 1,450 to 1,452.—Views of Triumph pole pieces. These consist of laminated punchings *securely clamped between* two cast steel end plates. The laminations are shaped with *polar horns or shoes as shown*, and which serve to keep the field coils securely wedged in *position. In some designs the horns are separate.* The two holes in each pole piece are *for through bolts which secure* the pole piece and coil to the spider rim. Dovetail joints *are sometimes used instead of through* bolts, as in figs. 1,448 and 1,449.

1. Self-excited;
2. Separately excited;
3. Compositely excited.

Ques. What is a self-excited alternator?

Ans. One in which the field magnets are excited by current from one or more of the armature coils, or from a separate winding (small in comparison with the main winding), the current being transformed into direct current by passing it through a commutator.

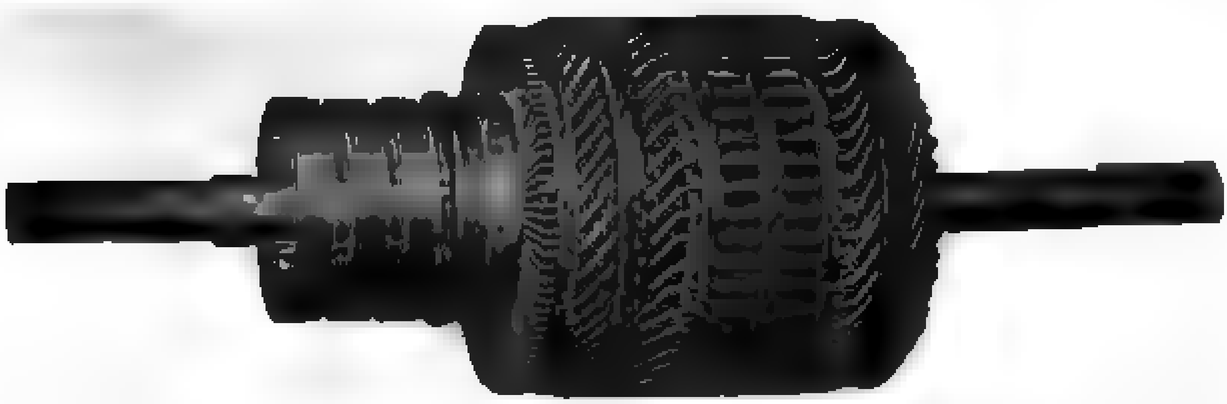


Fig. 1,453.—Fort Wayne armature for self-excited alternator. There are two independent windings, one for the main current, and one for the exciting current. The winding for the latter current occupies a very small amount of space, and is placed in the slots on top the main winding. The commutator to which the exciter winding is connected, is located between the collector rings and the core. It is of standard construction with end clamps holding the bars in place on the insulated commutator drum. The armature coils are form wound and the core is built of sheet steel laminations, annealed and japanned to prevent hysteresis and eddy current losses. Ventilated openings are provided to allow a free circulation of air both around the ends of the windings and through ducts in the laminated core. The core is clamped by bolts between the flanges of the armature spider which is keyed to the shaft. These flanges have cylindrical extensions with ribbed surfaces, which form a support for the ends of the armature coils. The ribbed surfaces form air passages from the core outward around the ends of the coils, thus ventilating both core and coils.

Fig. 1,453 shows an armature of a self-excited machine, the exciting current being generated in a separate winding and passed through a commutator.

Ques. For what class of service are self-exciting alternators used?

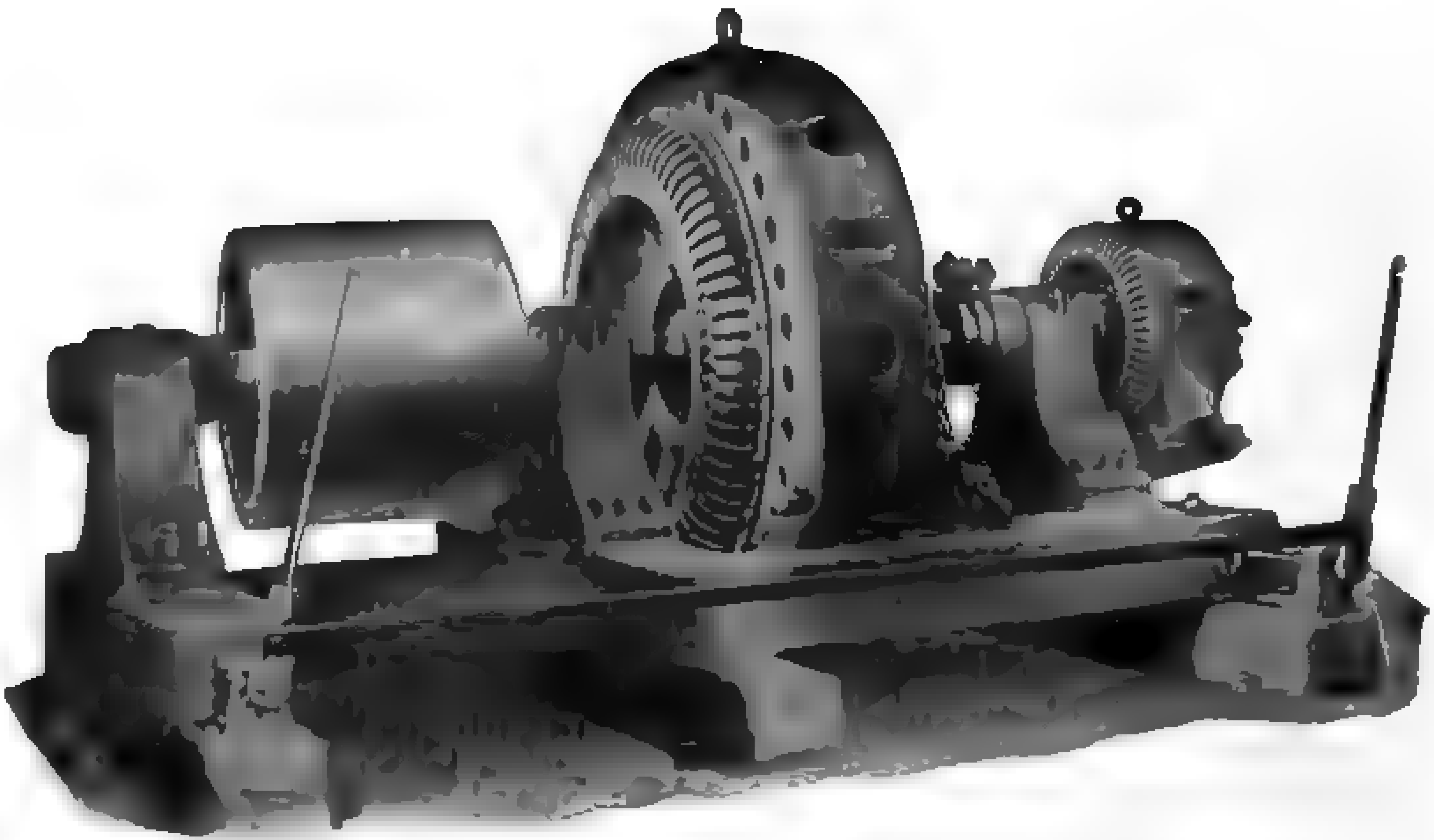


FIG. 1,454.—Allis-Chalmers three bearing type alternator with exciter direct connected. The bearing pedestals are bolted to a substantial cast iron base having, in the large sizes, sufficient length to permit shifting frame sideways along the base to give access to the field and armature coils. The field coils are designed for 120 volt excitation, and are wound edgewise with copper strip. There is a liberal margin of field excitation to take care of overloads or for operation on loads of low power factor. The regulating qualities are as good as can be obtained without making the machine unnecessarily large and expensive. By regulation is meant the percentage rise in voltage when full load is thrown off, field excitation and speed being held constant; the percentage is referred to normal full load voltage. An alternator with poor regulation will show large variations in voltage with changes in load, the pressure falling whenever a load is thrown on and rising when it is thrown off. These changes will be especially pronounced if the load be inductive. A badly designed alternator might show very fair regulation on non-inductive load and yet be unable to give full voltage on inductive load.

Ans. They are employed in small power plants and isolated ighting plants where inductive loads are encountered.

Ques. What is a separately excited alternator?

Ans. One in which the field magnets are excited from a small dynamo independently driven or driven by the alternator shaft, either direct connected or by belt as shown in fig. 1,455.

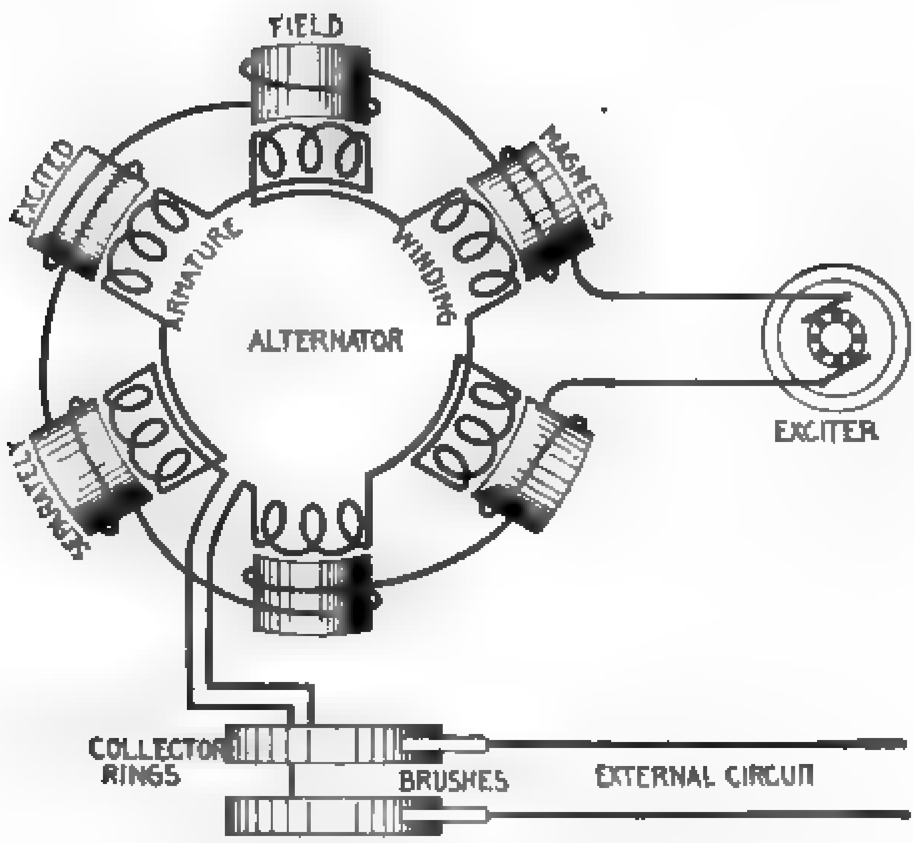


FIG. 1,455.—Diagram of separately excited alternator. The field winding is supplied with direct current, usually at 125 volts pressure by a small dynamo called the "exciter." The latter may be driven by independent power, or by belt connection with the main shaft, and in some cases the exciter is directly connected to the alternator shaft.

Ques. What is a compositely excited alternator?

Ans. A composite alternator is similar to a compound wound dynamo in that it has two field windings. In addition to the regular field coils which carry the main magnetizing current from the exciter, there is a second winding upon two or upon all of the

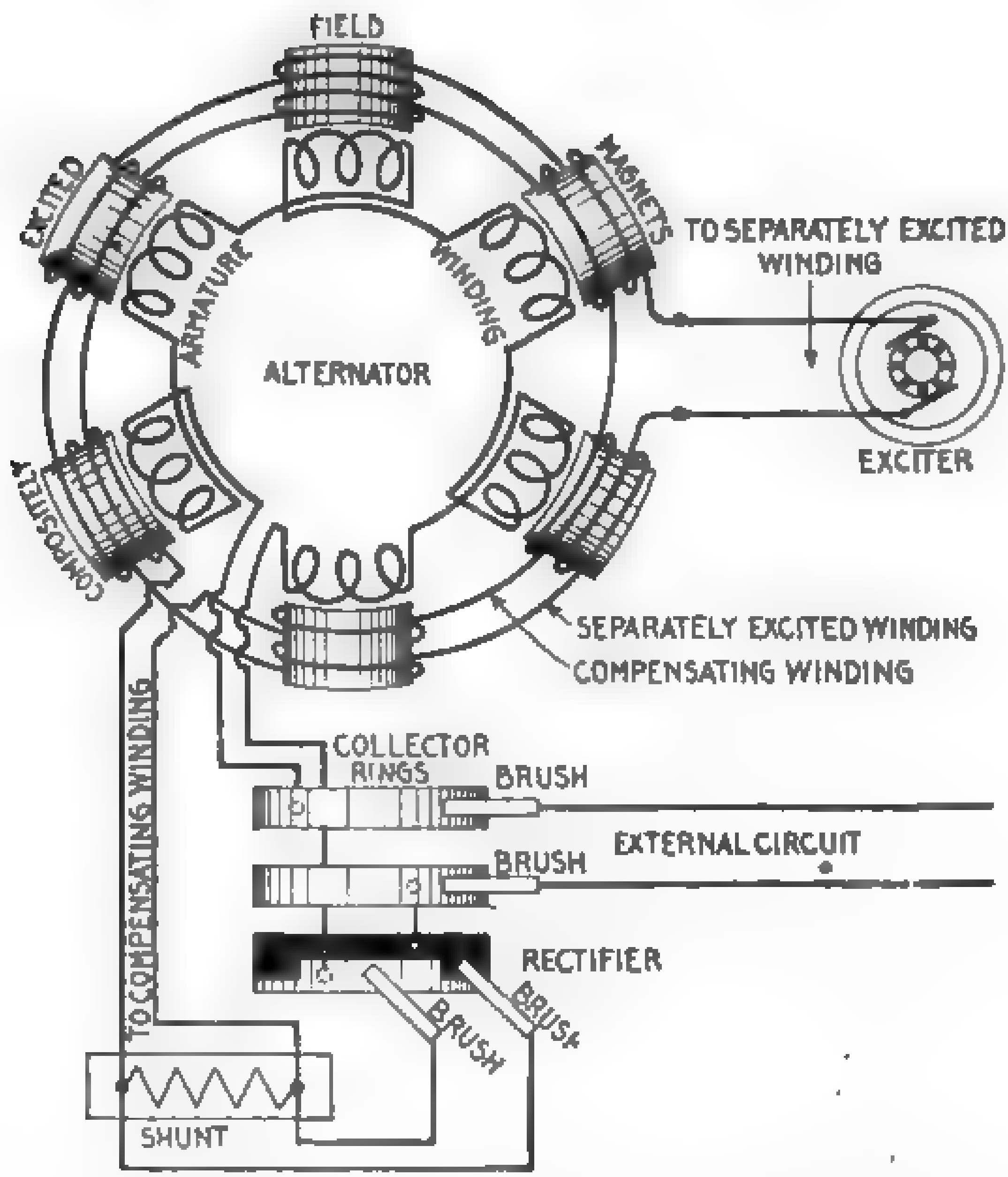


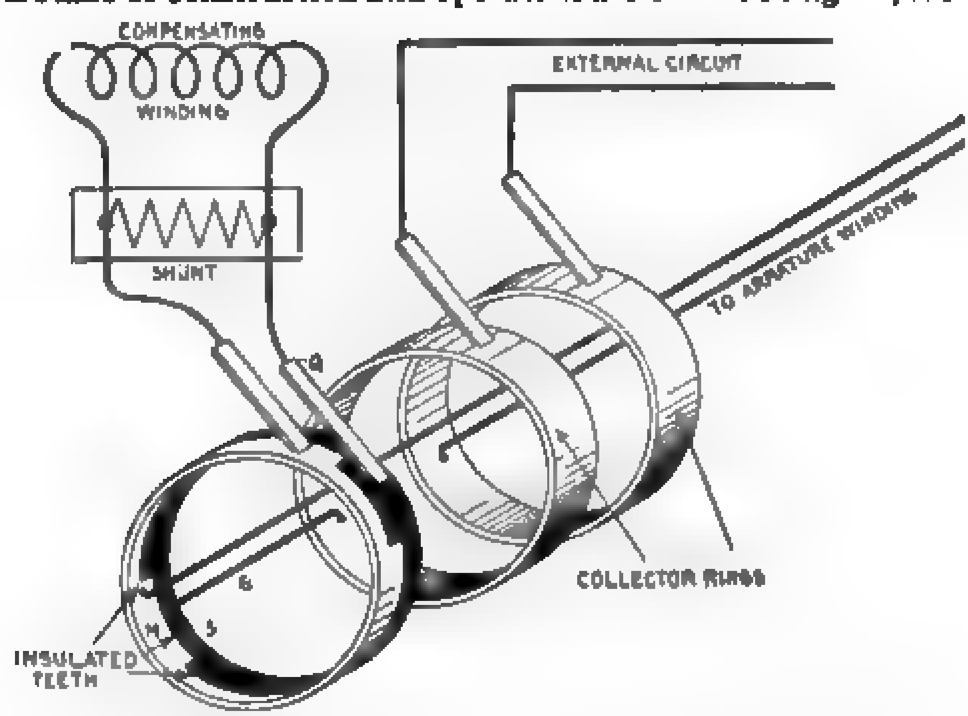
FIG. 1,456.—Diagram of compositely excited alternator. The current for exciting the field magnets is obtained, partly from an exciter and partly from the windings of the alternator, being transformed into direct current by the rectifier. The connections are as shown. One end of the armature winding is connected to one of the collector rings; the other end, to the light part of the rectifier, as shown, the solid black part of the rectifier being connected to the other collector ring. Two brushes bear on adjacent teeth of the rectifier and are connected to the compensating winding circuit across which is a shunt. These connections are shown more clearly in fig. 1,457. In operation the separately excited coils set up the magnetism necessary for the generation of the voltage at no load. The main current coming from the armature is shunted, part going through the shunts and the remainder around the compensating winding, furnishing the additional magnetism necessary to supply the voltage to overcome the armature impedance. This composite method of field excitation is very similar to that used on a compound wound dynamo. *As shown, both field windings encircle every pole, but in some machines the rectified current will traverse a few poles only*, the current from the exciter traversing the remainder.

pole pieces, carrying a rectified current from the alternator which strengthens the field to balance the losses in the machine, and also if so desired, the losses on the line as shown in fig. 1,456.

Ques. What is a magneto?

Ans. A special form of alternator having permanent magnets for its field, and used chiefly to furnish current for gas engine ignition and for telephone call bells.

Details of construction and operation are shown in figs. 1,458 to 1,461



.457 —Diagram showing construction of rectifier and connections of compositely excited ternator. The rectifier consists of two castings M and S with teeth which fit together , shown, being insulated so they do not come in contact with each other. Every alternate ooth being of the same casting is connected together, the same as though joined by a onducting wire. There are as many teeth as there are poles. One end of the armature winding is connected direct to one of the collector rings, while the other is connected to M of the rectifier, the circuit being through brushes P and Q, the shunt, and compensating winding to the other collector ring. The brushes P and Q contact with adjacent teeth, when one is in contact with the solid black casting the other touches the light casting. The principle of action is the same as a commutator, briefly: to reverse the connections terminating at the brushes P and Q in synchronism with the reversals of the alternating current induced in the armature winding, thus obtaining direct current for the compensating field winding. The shunt resistance placed across the compensating winding circuit permits adjusting the compounding of the machine to the circuit on which it is to work, since by varying the resistance the percentage of the total current passing through the compensating winding can be changed. It will be seen by tracing the path of the current for each direction in the armature winding that while the rectifier causes the current to flow in the same direction in the compensating field winding, it still remains alternating in the external circuit.

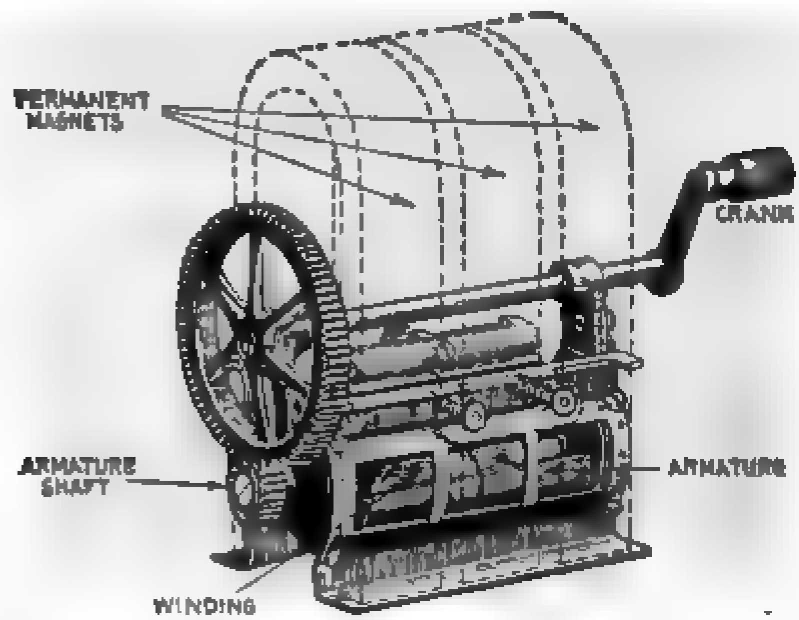
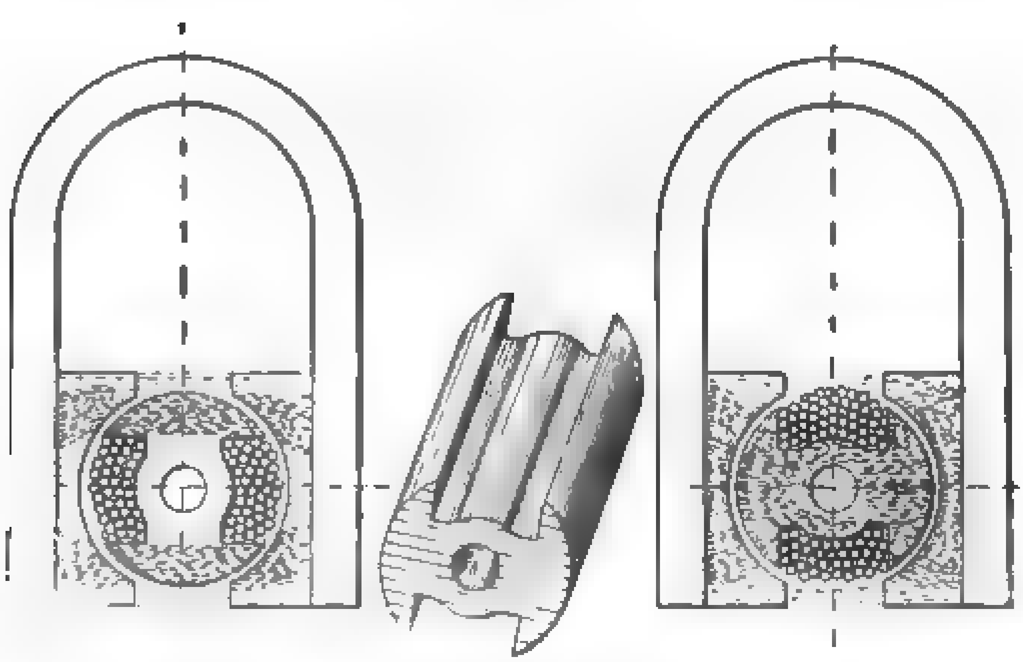


FIG. 1,458.—Connecticut magneto; view showing permanent magnets in dotted lines. It consists of three permanent U shape magnets, between the poles of which is a shuttle type armature. The latter is geared to a hand crank in sufficient velocity ratio to give the desired speed without too rapid turning of the crank. This type of magneto is used to generate current for operation of telephone call bells.



FIGS. 1,459 to 1,461.—Diagram illustrating the operation of a magneto. The shuttle shaped armature is wound from end to end with insulated wire, so that when rotated, a powerful alternating current is produced in the windings by cutting the magnetic lines, whose varying strength is shown by the shaded portions in the two views. When in the position shown in the first diagram, the lines of force mostly converge at the top and bottom, finding a direct path through the metal end flanges of the shuttle. When in the position shown in the *second diagram*, the lines are converged so as to pass through the armature core. *Fig. 1,460 shows detail* of the armature core.

Ques. What are the two principal types of field magnet?

Ans. Stationary and revolving.

Ques. What is the usual construction of stationary field magnets?

Ans. Laminated pole pieces are used, each pole being made up of a number of steel stampings riveted together and bolted or

FIG. 1,462.—Stationary field of Fort Wayne multiphase revolving armature alternator, view showing brass girds on pole pieces for synchronous motor operation. When designed for this use the machine is provided with amortisseur winding on the poles. As shown in the illustration this winding consists of a brass collar around the pole tip with a cross rib integral with the collar, fitting in a slot in the pole face parallel to the shaft. This construction assists in bringing the machine up to synchronous speed as an induction motor, ordinarily checks any tendency toward hunting and does not in any way affect the operation of the machine as an alternator. The main field winding should be connected through switches on the field frame in order that the field circuit may be broken up to eliminate any danger that might arise from induced voltage. It is not advisable to throw on a full rated voltage and a compensator should, therefore, be provided to reduce the pressure.

preferably cast into the frame of the machine. The field coils are machine wound and carefully insulated. After winding they are taped to protect them from mechanical injury. Each coil is then dipped in an insulating compound and afterwards baked to render it impervious to moisture.

FIG. 1,463.—Triumph 36 pole fly wheel type revolving field. The spider has the form of a fly wheel having spokes and rim to which the field magnets are attached by through bolts. The field coils are of copper strap bent on end, the kind generally used on large machines. The series connection of the coils is plainly shown, also the two cables leading via one of *the spokes to the slip rings.*

Ques. Describe the construction of a revolving field.

Ans. The entire structure or rotor consists of a shaft, hub or spider, field magnets and slip rings. The magnet poles consist of laminated iron stampings clamped in place by means of through bolts which, acting through the agency of steel end plates, force the laminated stampings into a uniform, rigid mass. This mass is magnetically sub-divided into so many small parts that the heating effect of eddy currents is reduced to a minimum. The cores are mounted upon a hub or spider either by dovetail construction or by means of through bolts, according to the centrifugal force which they must withstand in operation, either method permitting the easy removal of any particular

FIG. 1,464.—Wagner cast steel hub with dovetail grooves for attaching the revolving field magnets. Such construction is generally used on machines of small and medium size.

FIG. 1,465.—Wagner laminated pole piece with horns stamped in one piece. The laminations are held together between two end pieces by through rivets, as shown.

field pole if necessary. The field coils are secured upon the pole pieces either by horns in one piece with the laminations, or separate and bolted. All the coils are connected in series, cable leads connecting them to slip rings placed on the shaft.

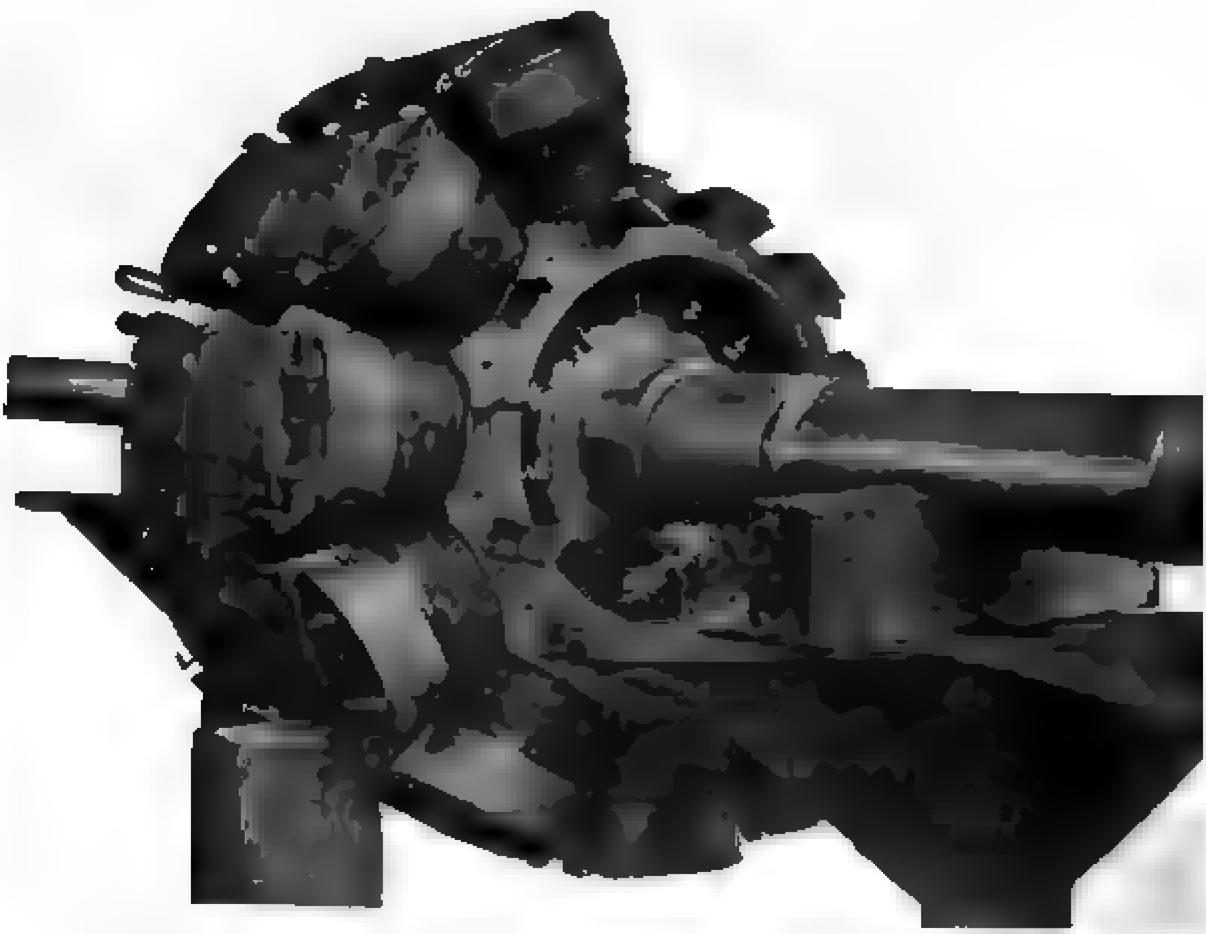


FIG. 1,466.—Wagner revolving field of 300 kilowatt alternator during construction, illus trating the method of attaching the field magnets to the hub by dovetail joints. After the notched ends of the pole pieces are slided into the grooves in the hub, tapered keys which are plainly seen, are driven in, thus making a tight joint which will not shake loose

Ques. What are slip rings?

Ans. Insulated rings mounted upon the alternator shaft to receive direct current for the revolving field, as distinguished from collector rings which collect the alternating currents generated in an alternator of the revolving armature type.

In construction provision is made for attaching the field wind leads. *The rings* are usually made of cast iron and are suppo

mechanically upon the shaft, but are insulated from it and from one another.

The current is introduced by means of brushes as with a commutator. Carbon brushes are generally used.

A good design of slip ring should provide for air circulation underneath and between the rings.

FIG. 1,467.—General Electric field coil, showing one method of winding. In the smaller machines the wire is wound on spools which are slipped over the pole pieces, which are built of sheet iron, spreading at the pole face so as to secure not only a wide polar arc for the proper distribution of the magnetic flux, but also to hold the field windings in place.

Ques. What rm of spider is ed on large alter-tors?

Ans. It is prac-ally the same form as a fly wheel, consisting of hub, spokes, and rim to which the magnets are bolted.

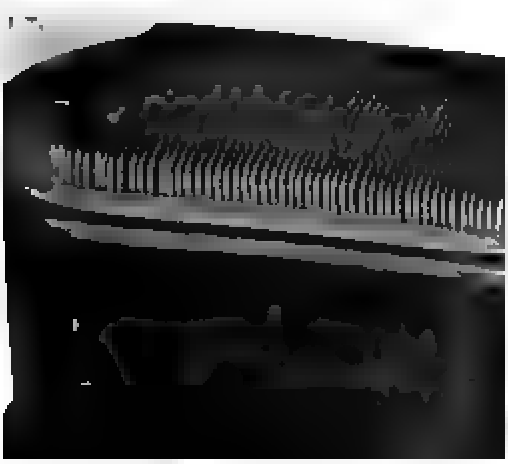
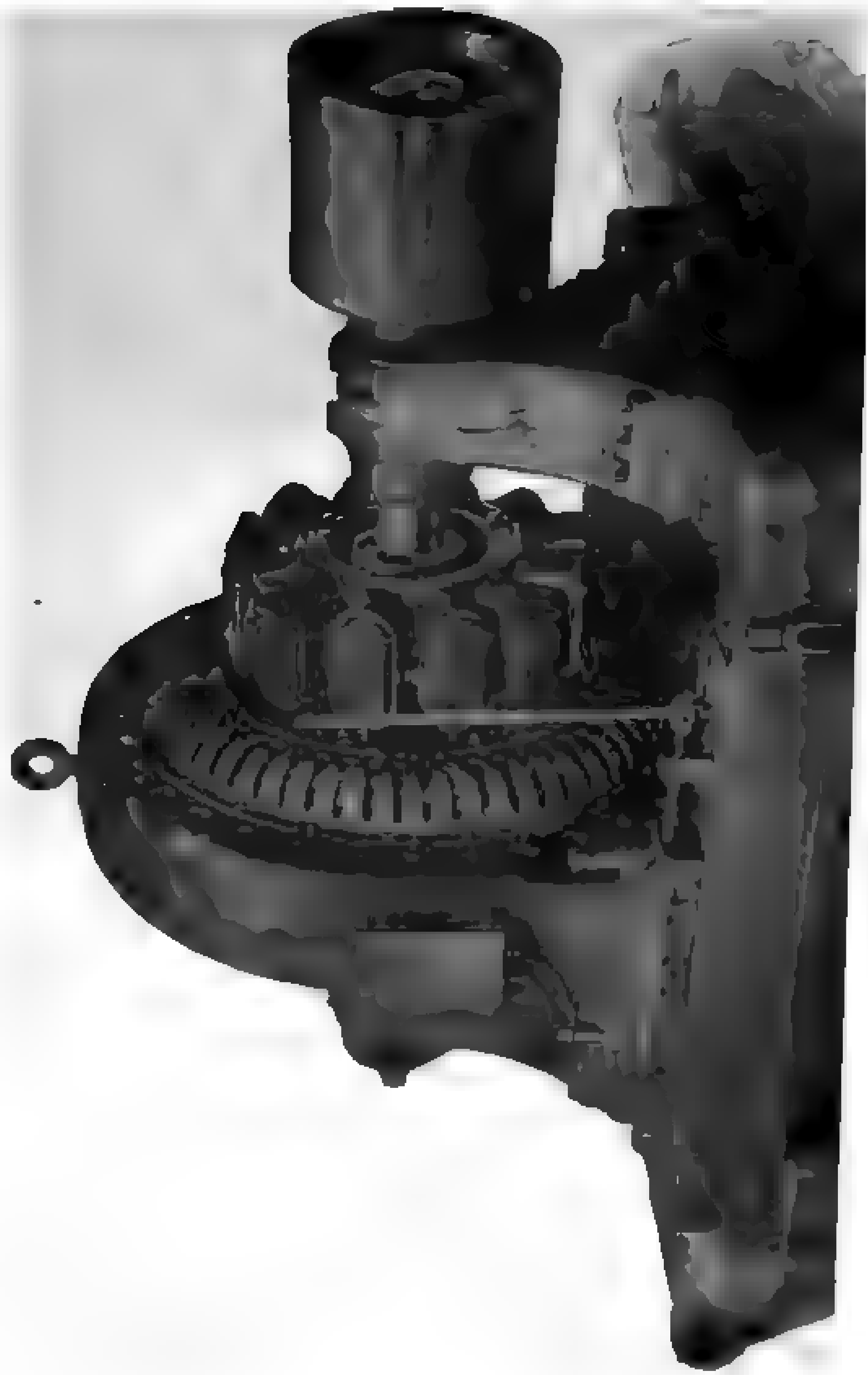


FIG. 1,468.—General Electric field coil showing another method of winding. The field coils on the larger machines consist of a single strip of flat copper, wound on edge as shown, so that the surface of every turn is exposed to the air for cooling. The flat sides of the copper strip rest against each other and the entire coil forms a structure of great solidity which can be easily removed for inspection and repair.



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On alternators of the fly wheel type the spider rim is made of sufficient weight to obtain full fly wheel effect, thus making a separate fly wheel unnecessary.

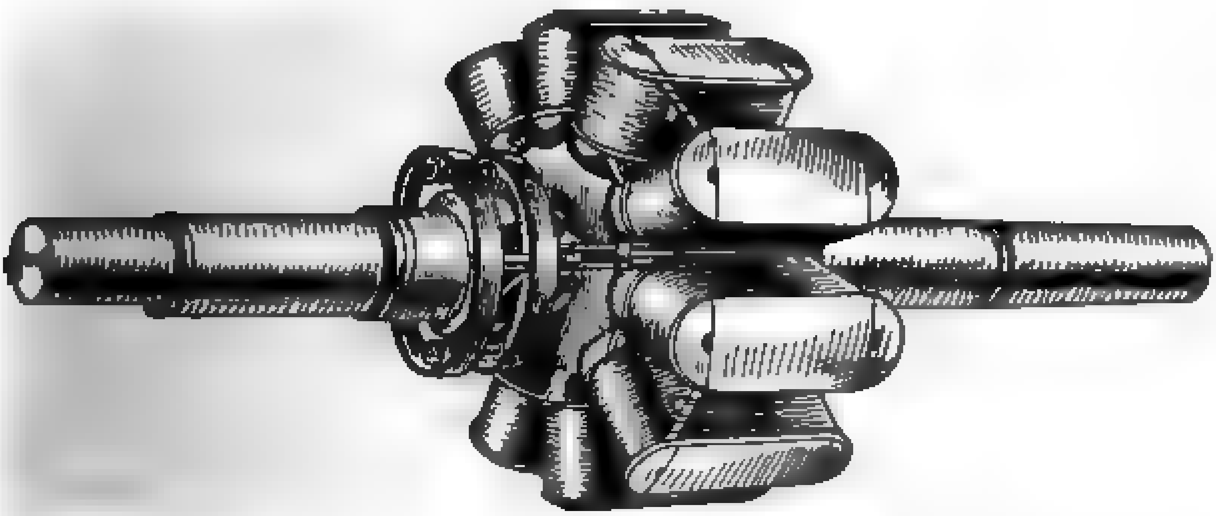


FIG. 1,470.—Revolving field of Fort Wayne 10 pole alternator. In construction, the cores of the field poles are built up from punchings of laminated steel, and assembled under considerable pressure between malleable iron or steel end plates and riveted together. Substantial insulation is placed on the pole cores and over this is wound the field coils of cotton covered wire. After the wire is in place, the completed poles are baked to expel any moisture and are then treated with insulating varnish. They are then assembled on a laminated spider, being held in place by dovetail joints made tight by the use of taper keys. Special casting plates are finally fastened in place over the dove tails effectually closing them. The assembly of the field is completed by the insertion of the shaft into the field spider under heavy hydraulic pressure. All the coils are connected in series, cable leads connecting them to slip rings placed on the shaft. Each slip ring is provided with a double type brush holder, making it possible to clean brushes while the alternator is in service, by simply removing one brush at a time.

FIG. 1,471.—General Electric slip rings; view showing construction and attachment of cable leads to field winding. They are so designed that all surfaces of the rings have easy access to the air, in order to obtain good ventilation. *Slip rings*, through which current is transmitted to a revolving field, are to be distinguished from *collector rings* whose function it is to "collect" or transmit the alternating currents induced in the armature to the brushes.

Armatures.—In construction, armatures for alternators are imilar to those employed on dynamos; they are in most cases impler than direct current armatures due to the smaller number f coils, absence of commutator with its multi-connections, etc. lternator armatures may be classified in several ways:

1. With respect to operation, as

   a. Revolving;
   b. Stationary.

FIG. 1,472.—Allis-Chalmers brush holder and slip rings. The latter are made of cast copper, which the builders claim to be more satisfactory than cast iron. On some of the large low speed machines the collector rings are split, but on the majority of alternators they are in one piece. Current is led into the rings by means of carbon brushes, the number of brushes being such that the current density at the rubbing contact is kept within conservative limits. At least two brushes per ring are provided, so that one can be removed for inspection without interrupting the exciting current. In large machines the brush holder studs are mounted on a stand supported from the base; on small alternators they are usually fastened to the cap of one of the bearing pedestals.

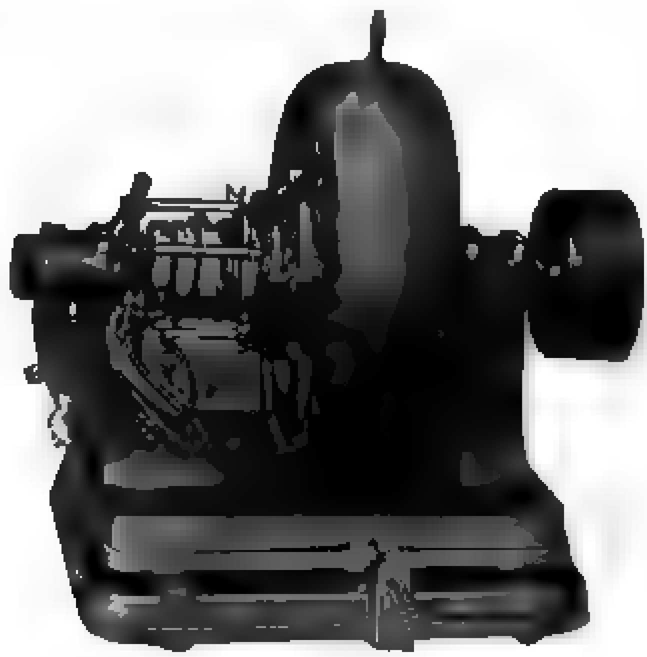
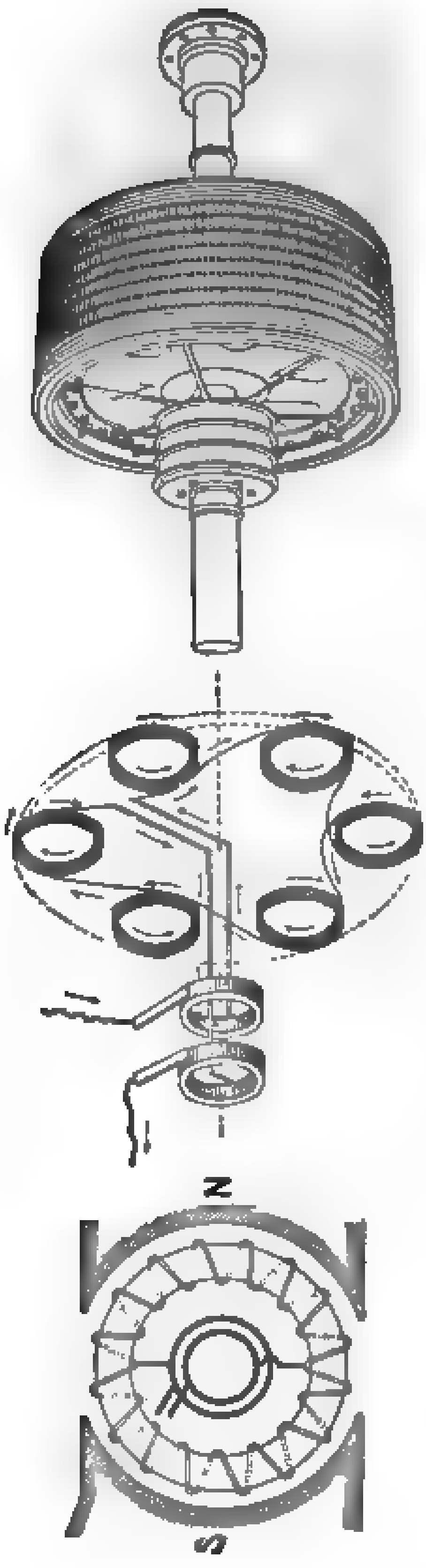


FIG. 1,473.—Fort Wayne multiphase revolving armature alternator, designed for use in small power plants and isolated lighting plants where inductive loads are encountered. Built for pressures of 120, 240, 480, and 600 volts. These voltages have been recommended by the American Institute of Electrical Engineers, and will cover the needs of any set of conditions ordinarily met with. These standard voltages not only permit economical distribution, but they are such that no transformers are necessary to reduce the line pressure for ordinary cases. For transmitting power relatively long distances, 600 volts is usually employed. Where there is a demand for 480 volt service, a 480 volt alternator should be selected and if lower voltages are also desired an auto-transformer may be furnished by means of which 240 volts can be obtained. When 120 volt circuits are necessary for lighting, etc., the 240 volt pressure can be still further reduced to 120 volts by means of another auto-transformer. However, this double reduction will rarely be found necessary.

FIG. 1,474.—Western Electric stationary armature. In this type of armature, the core upon which the winding is placed, is built into the frame as shown, the core teeth projecting inwardly like internal gear teeth, forming a cylindrical chamber for the revolving field. The core is built up of iron, laminated and japanned to prevent eddy currents and hysteresis losses. The laminations are rigidly bolted between two heavy end plates. The armature coils are of copper bar impregnated with insulating compound. They are held in the slots by wedges which allow their ready removal for inspection or repairs.



RING TYPE DISC TYPE DRUM TYPE

FIGS. 1,474 to 1,477.—Various types of armature; fig. 1,474 ring armature; fig. 1,475 disc armature; fig. 1,476 drum armature. The latter type is now almost universally used, the others being practically obsolete. A Gramme ring wound and connected to collector rings as in fig. 1,474, will yield an alternating current. In a multipolar field, the ring will need multipolar connections alternated at points corresponding to the pitch of the poles. Fig. 1,475 illustrates the so-called "Siemens" disc armature. The armature coils are arranged around the periphery of a thin disc. The field magnets consist of two crowns of fixed coils, with iron cores arranged so that their free poles are opposite one another. This type was created in 1878 by Herr von Hefner, engineer to Messrs. Siemens and Halske. Fig. 1,476 shows a modern drum armature of a three phase machine. It is similar in appearance to a direct current armature except for the absence of the commutator and its connections. The drum armature is the prevailing type.

2. With respect to the core, as

a. Ring;
b. Disc;
c. Drum.

Ring and disc armatures are practically obsolete and need not be further considered. A ring armature has the inherent defect that the copper inside the ring is inactive.

Disc armatures were employed by Pacinotti in 1878, and afterwards adopted by Brush in his arc lighting dynamos.

The design failed for mechanical reasons, but electrically it is, in a sense, an improvement upon the Gramme ring, in that inductors on both sides of the ring are active, these being connected together by circumferential connectors from pole to pole, thus, corresponding to the end connections on modern drum armatures.

3. With respect to the core surface, as

a. Smooth core;
b. Slotted core.

In early dynamos the armature windings were placed upon an iron core with a smooth surface. A chief disadvantage of this arrangement is that the magnetic drag comes upon the inductors and tends to displace them around the armature. To prevent

FIG. 1,478.—A style of disc largely used for armature cores. The teeth are provided with dovetail grooves near the circumference. After the coil is inserted in a groove, a wooden wedge is driven in the groove which encloses the coil and secures it firmly in position. This obviates the necessity of bands to resist the centrifugal force acting on the inductors.

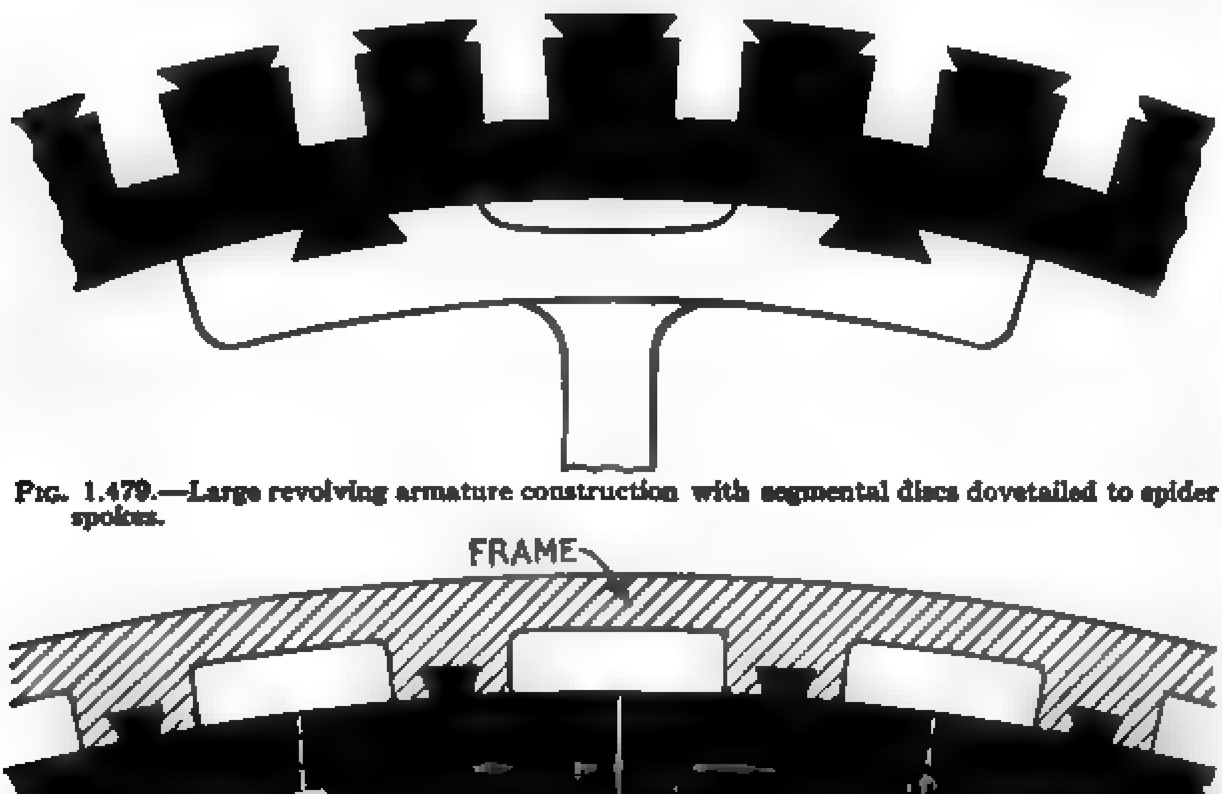


FIG. 1,479.—Large revolving armature construction with segmental discs dovetailed to spider spokes.

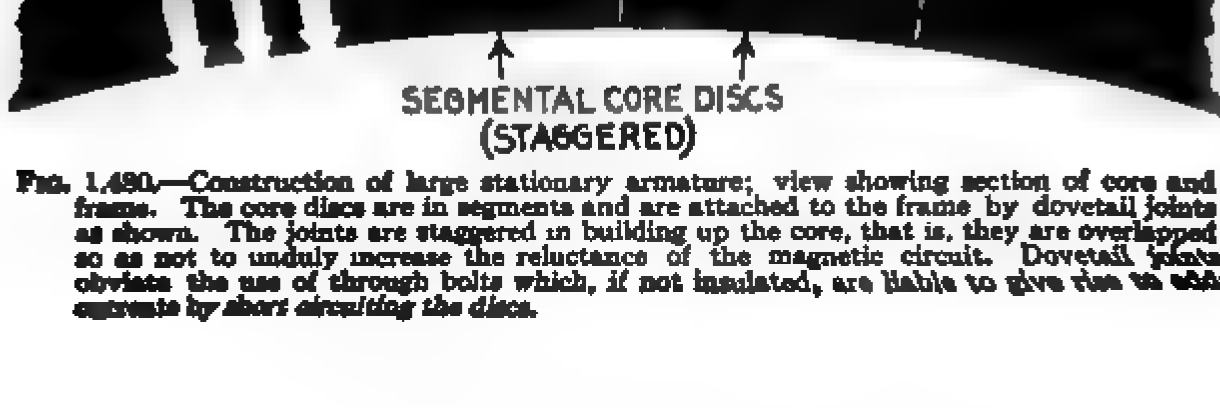


FIG. 1,480.—Construction of large stationary armature; view showing section of core and frame. The core discs are in segments and are attached to the frame by dovetail joints as shown. The joints are staggered in building up the core, that is, they are overlapped so as not to unduly increase the reluctance of the magnetic circuit. Dovetail joints obviate the use of through bolts which, if not insulated, are liable to give rise to eddy currents by short circuiting the discs.

this, projecting metal pieces called *driving horns* were fixed into the core so as to take the pressure, but they proved unsatisfactory. This defect together with the long air gap necessary in smooth core construction resulted in the type being displaced by slotted core armatures.

A slotted core is one whose surface is provided with slots or teeth which carry the inductors, as shown in the accompanying illustrations, and is the type almost universally used. The inductors are laid in the slots, the sides and bottoms of which are first carefully insulated by troughs of mica-canvas, micanite or other suitable insulating material.

Ques. What are the advantages of slotted core armatures?

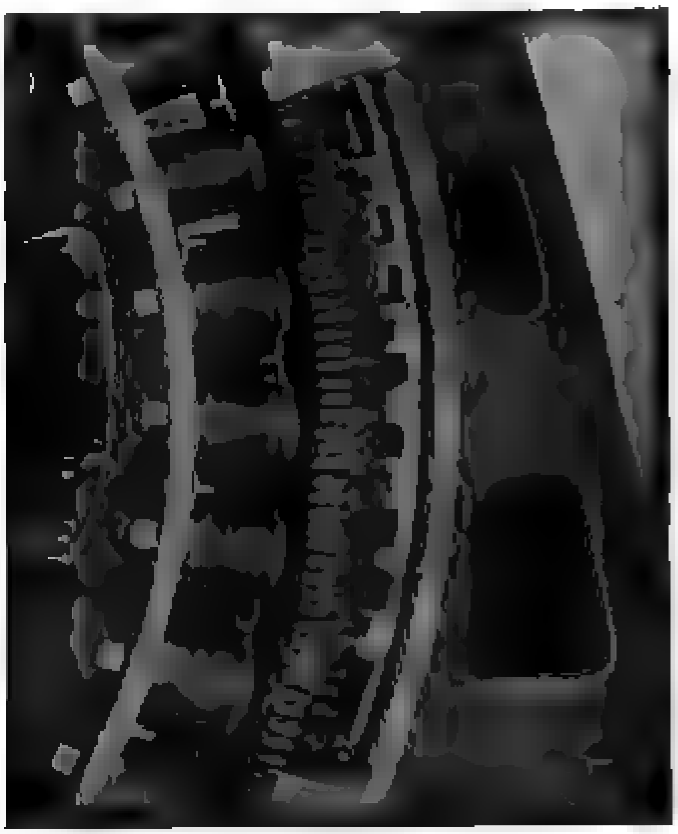
Ans. The teeth protect the inductors, retain them in place against the electrical drag and centrifugal force, and the con-

FIG. 1,481.—General Electric revolving field and exciter armature. This is an example of direct connected exciter construction. In this arrangement the armature of the exciter is carried on the alternator shaft at the end farthest from the pulley. In the smaller sizes the magnet frame is bolted to the bearing bracket, but in the larger sizes special construction is used depending upon the conditions to be met. On all alternators of standard design, the field is built for 125 volts excitation and on account of the increased danger from induced voltage, in case the machine is used as a synchronous motor, the builders consider any higher voltage undesirable.

struction permits a reduction of air gap to a minimum, thus reducing the amount of copper required for the field.

Armature Windings.—In general, the schemes for armature windings for alternators are simpler than those for direct current machines, as in the majority of cases the inductors are an even multiple of the number of poles, and the groupings are usually symmetrical with respect to each pole or each pair of poles. Furthermore, as a general rule, all the inductors of any one phase are in *series with one* another; therefore, there is only one circuit per

ase, and this is as it should be, since alternators are usually quired to generate high voltages. These general principles ablish the rule, that in the circuit in a single phase armature, l in the individual circuits in a polyphase armature, the



1,482.—Section of General Electric Alternator showing method of dovetailing core laminations to frame. The latter is made in two general styles, known as the *box type* and *skeleton type*. The box type consists of a single casting for the smaller sizes, but for large capacity alternators the frame castings are usually divided into upper and lower sections. The skeleton type consists of two side castings between which substantial spacing rods are set at regular intervals. The core consists of the usual sheet iron lamination slotted and assembled; they are mounted on the inner periphery of the frame, making lap joints (that is "staggered" as in fig 1,480), each section being dovetailed to the frame. Heavy clamping rings or end plates are mounted on both sides of the core by means of bolts, and supporting fingers extend along the slot projections. The design is such as to provide for air circulation as shown in figs. 1,483 and 1,484.

ding is never re-entrant, but the circuits have definite endings l beginnings. In exceptional cases, as those of polyphase verters, re-entrant circuits are employed, and the armature dings *are so constructed* that a commutator can be

connected to them exactly as in direct current machines. These armatures are usually of the lap wound drum type.

Alternator windings are usually described in terms of the number of slots per phase per pole. For instance, if the armature of a 20 pole three phase machine have 300 slots it has 15 slots

FIG. 1,483. Section of General Electric alternator frame showing air ducts and supporting fingers extending along the slot projections. The air circulation is provided for by means of ducts formed by suitable spacing blocks inserted at intervals between the laminations, as shown here and in fig. 1,484. The armature coils are form wound and designed so they can be readily replaced in case of injury. They are taped and treated with an impregnating compound, in the usual way, then inserted in the armature slots in an armour of horn fibre and retaining wedges of wood are dovetailed into the slot walls.

per pole or 5 slots per each phase per pole, and will be described as a five slot winding. Therefore, in order to trace the connections of a winding, it is necessary to consider the number of slots *per pole for any* one phase, on one of the following assumptions:

1, that each slot holds one inductor; 2, that there is one side of a coil in each slot; and 3, that one side of a coil is subdivided so as to permit of its distribution in two or more adjacent slots.

The voltage depends upon the number of inductors in a slot, but the breadth coefficient and wave form are influenced by the number of slots per pole, and not by the number of inductors within the slots.

FIG. 1,484.—Section of General Electric stationary armature showing method of assembling the coils. These are form wound and are held in the slots by suitable wedges, the open slot construction permitting the use of form wound coils that can be easily removed and replaced in case of damage. Where heavy windings project beyond the laminations, an additional support is provided by means of an insulated metal ring, to which the outer ends of the coils are fastened; the coils are thereby protected from mechanical displacement, or distortion due to the magnetic disturbances caused by violent fluctuations of the load or short circuits. The figure shows a section of a supporting ring of this type and indicates the method of connecting the coils to it. In order to admit of the prompt replacement of damaged coils, sufficient space is usually provided between the alternator bearings to allow ample movement of the armature to permit of ready access to both armature and field coils. Where space necessitates the use of a short shaft, access to the windings may be had by disconnecting some of the coils and lifting the upper half of the armature.

Classification of Windings.—The fact that alternators are built in so many different types, gives rise to numerous kinds of armature winding to meet the varied conditions of operation. In dividing these forms of winding into distinctive groups, they may be classified, according to several points of view, as follows:

1. With respect to the form of the armature, as:

    a. Revolving;
    b. Stationary.

2. With respect to the mode of progression, as:

    a. Lap winding;
    b. Wave winding.

3. With respect to the relation between number of poles and number of coils, as:

    a. Half coil winding;
    b. Whole coil winding.

4. With respect to the number of slots, as:

    a. Concentrated or uni-coil winding;
    b. Distributed or multi-coil winding.

        Partially distributed;
        Fully distributed.

5. With respect to the form of the inductors, as:

    a. Wire winding;
    b. Strap winding;
    c. Bar winding.

6. With respect to the number of coils per phase per pole, as:

    a. One slot winding;
    b. Two slot winding;
    etc.

7. With respect to the kind of current delivered, as:

a. Single phase winding;
b. Two phase winding;
c. Three phase winding.

FIG. 1,485.—Section of Western Electric stationary armature core showing laminations clamped in place, and ventilating ducts. The stator or stationary armature consists of soft iron laminations assembled in the magnet frame with stator coils embedded in the core slots. The laminations are punched separately and then carefully annealed to reduce hysteresis losses. After annealing, a coat of japan is applied, effectively preventing the flow of eddy currents in the assembled core. The frame is cast iron and of the box type construction. The frames of the smaller sizes are cast in one piece, while frames of the larger sizes are split to facilitate installation. Large openings are provided in the box type frame, in order to improve the ventilation. The laminations are securely held in place in the frame by heavy end rings and by steel clamping fingers which are firmly bolted to the frame. The outer circumference of the core is dovetailed to the frame, and the inner circumference is slotted to receive the windings. The alignment of the slots is insured by means of metal wedges, and no filing is done on the slots, so that each lamination is always insulated from the next one. Numerous ventilating ducts allow the free circulation of cool air through and around the coils. The open slot construction is employed and the coils are fitted into insulating troughs which offer excellent mechanical and electric protection. The coils are held in place by suitable wedges.

8. With respect to the shape of the coil ends, as:

a. Single range;
b. Two range;
etc.

In addition to these several classes of winding, there are a number of miscellaneous windings of which the following might be mentioned:

a. Chain or basket winding;
b. Skew coil winding;
c. Fed-in winding;

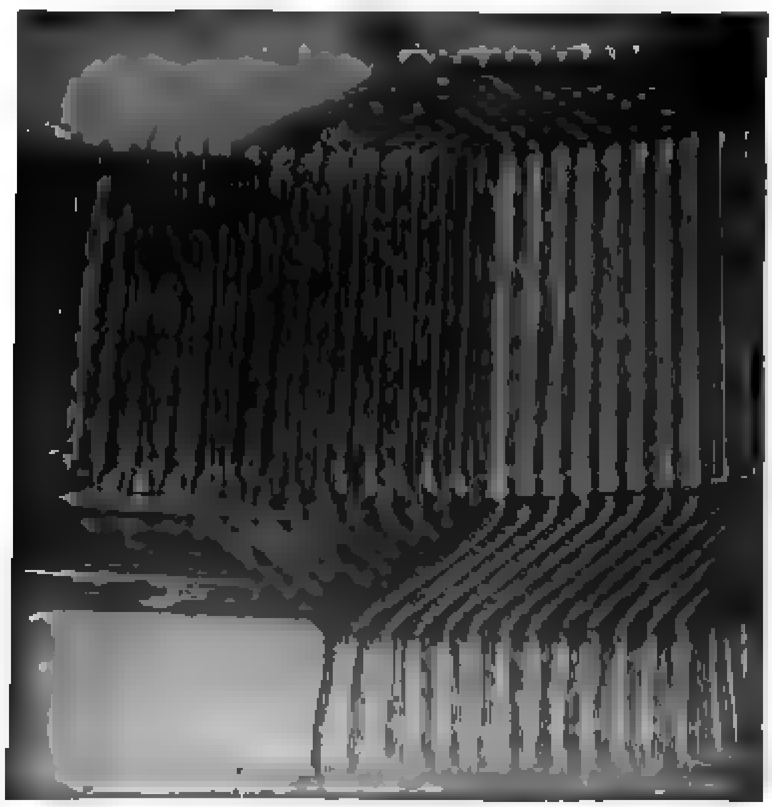


Fig. 1,486.—Method of assembling form wound coils. The picture shows a section of a General Electric armature with part of the coils in place. A layer of insulating material is first placed in the slots before inserting the coils as seen at the left. When the coils are in place and surrounded by this layer of insulating material the retaining wedges are inserted in the notches, thus closing the slots and protecting the coils from mechanical injury. A few wedges are seen in position at the right.

d. Imbricated winding;
e. Mummified winding;
f. Spiral winding;
g. Shuttle winding;
h. Creeping winding;
i. *Turbine* alternator winding.

Ques. Define a revolving and a stationary winding.

Ans. The words are self-defining; a winding is said to be revolving or stationary according as the armature forms the rotor or stator of the machine.

Ques. What is the significance of the terms lap and wave as applied to alternator windings?

Ans. They have the same meaning as they do when applied to dynamo windings.

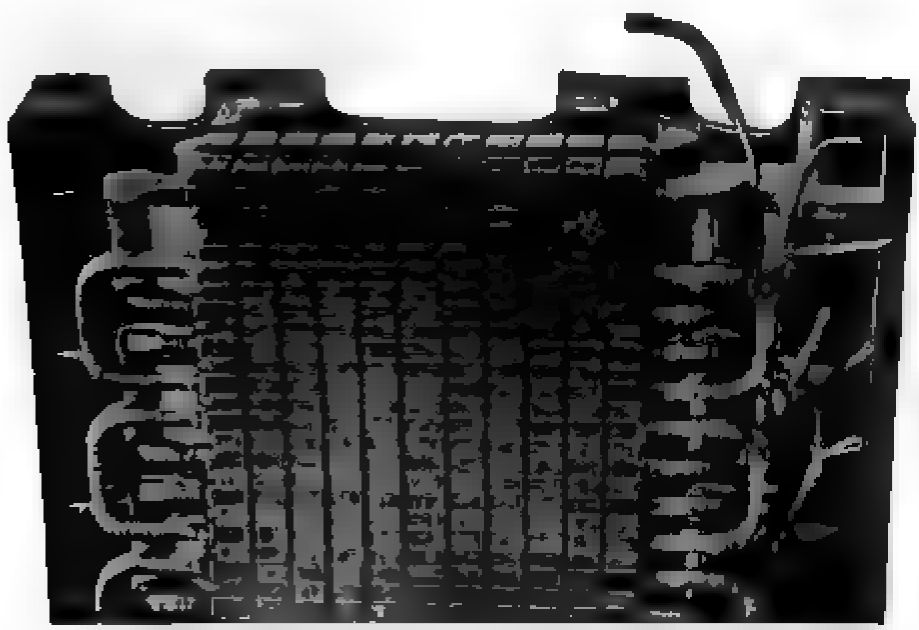


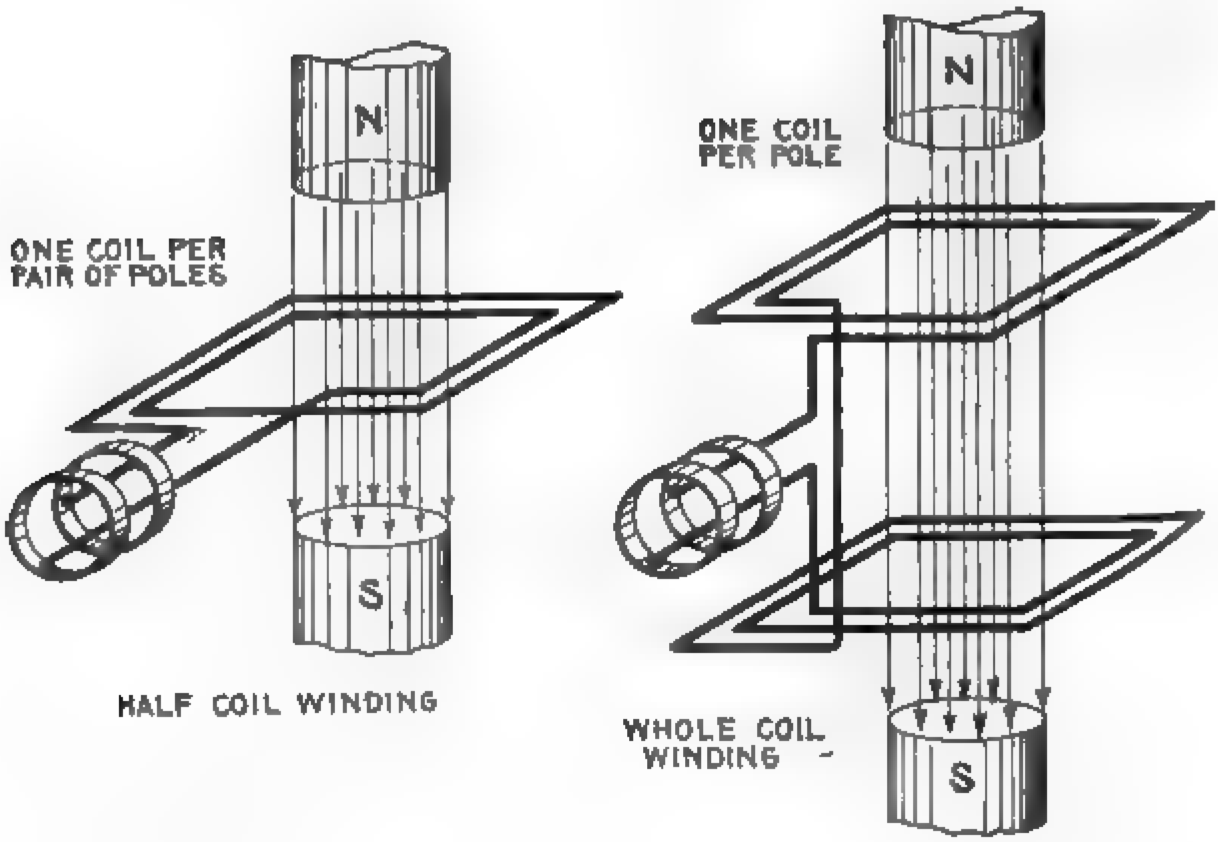
FIG. 1,487.—Section of General Electric stationary armature ventilating ducts and winding in position.

These are described in detail in Chapter XVIII. Briefly a lap winding is one composed of lap coils; a wave winding is one which roughly resembles in its diagram, a section of waves.

Half Coil and Whole Coil Windings.—The distinction as to whether the adjacent sides of consecutive coils are placed together under one pole or whether they are separated a distance equal to the pole pitch, gives rise to what is known as **half coil and whole coil windings.**

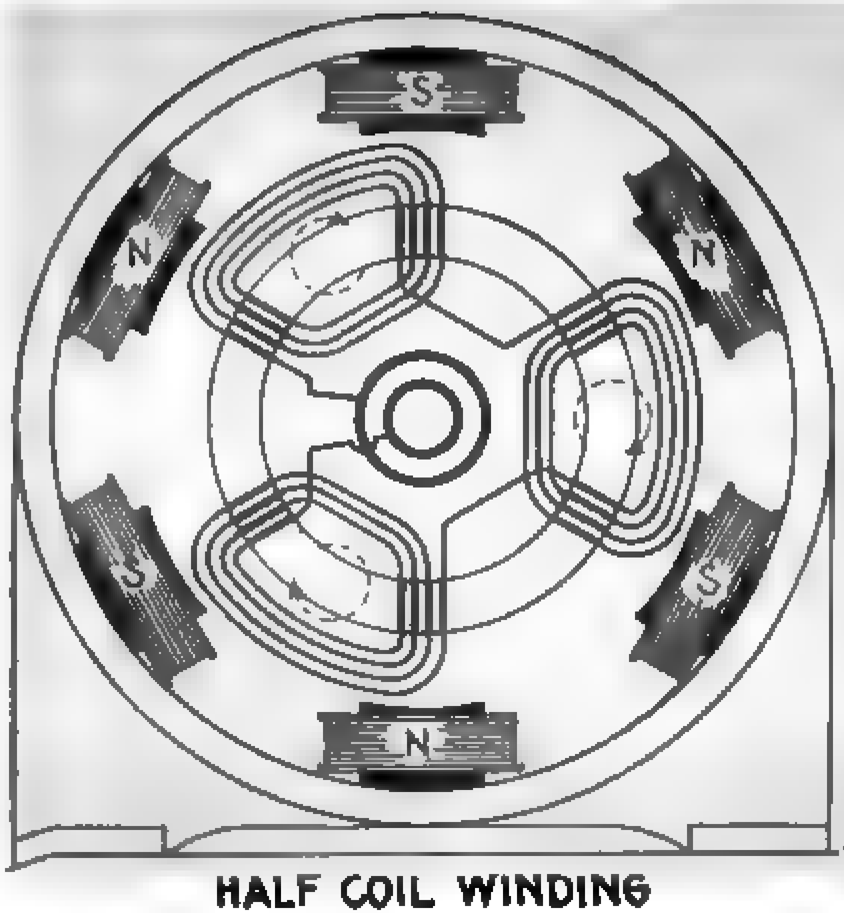
A half coil or hemitropic winding is *one in which the coils in any phase are situated opposite every other pole,* that is, *a winding in which there is only one coil per phase* **per pair of poles,** as in fig. 1,488.

A whole coil winding is one in which there is one coil per phase **per pole,** as in fig. 1,489, the whole (every one) of the poles being subtended by coils.



FIGS. 1,488 and 1,489.—Elementary bipolar alternators with *half coil* and *whole coil* windings. In a half coil winding there is one coil per phase *per pair of poles*; in a whole coil winding there is one coil per phase *per pole.*

Concentrated or Uni-Coil Winding.—Fig. 1,492 shows the simplest type of single phase winding. It is a one slot winding and is sometimes called "monotooth" or "uni-coil" winding. The surface of the armature is considered as divided into a series of large teeth, one tooth to each pole, and each tooth *is wound with* one coil, of one or more turns per pole. Since



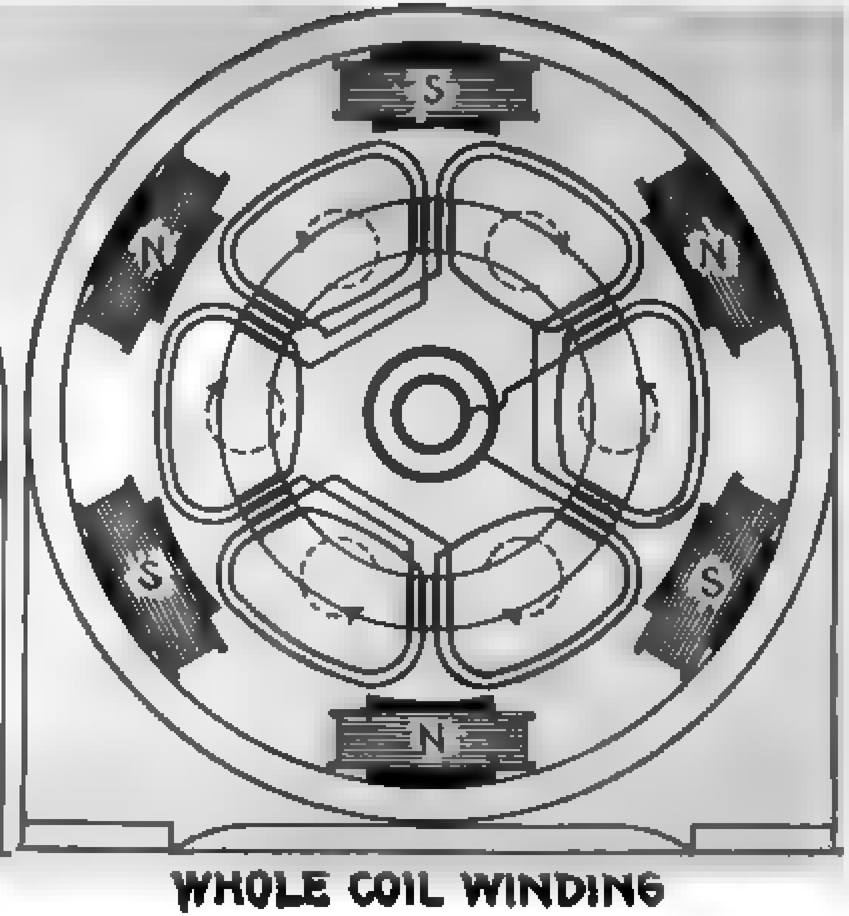


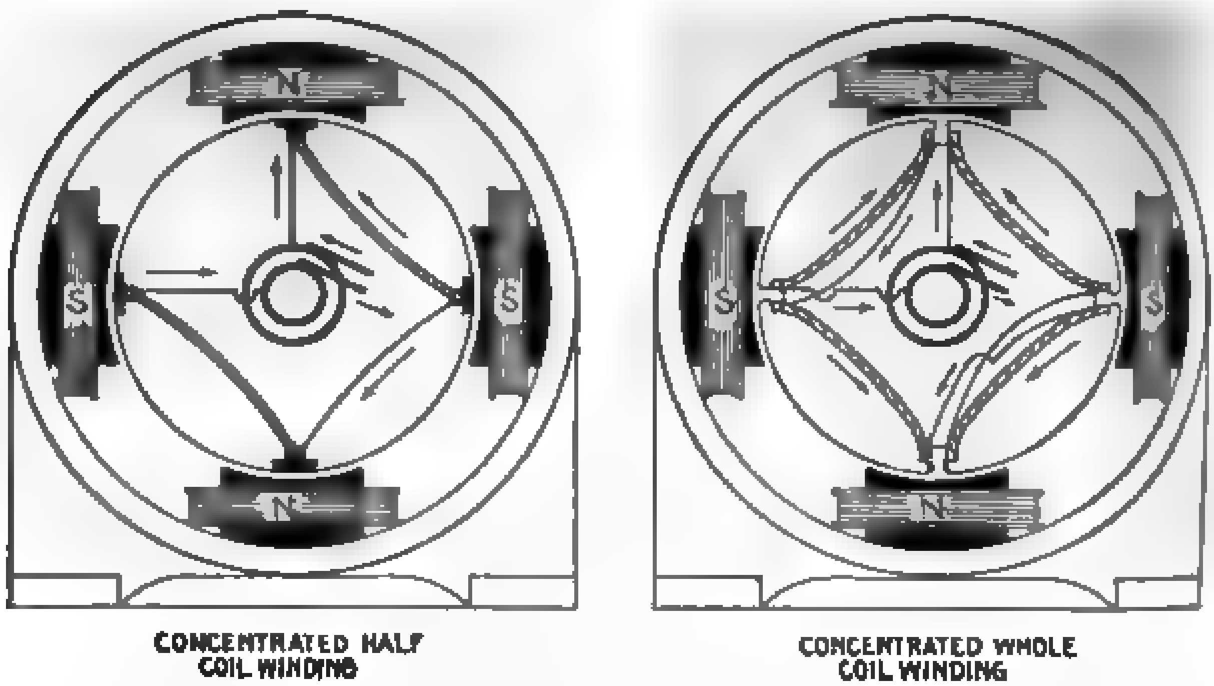
FIG. 1,490.—Multi-polar revolving armature alternator with half coil winding, shown in radially developed diagram to clearly indicate the path of the winding. A half coil or hemitropic winding has a slightly higher reactance than a winding in which two distinct coils are used in the same slot, one going forward and the other backward. The most usual three phase windings are of the half coil type as the three sets of coils are equispaced over a pair of poles.

FIG. 1,491.—Multi-polar revolving armature alternator with whole coil winding shown in radially developed diagram to clearly indicate the path of the winding.

all the turns of the coil are placed in single slots, the winding is called "concentrated."

Ques. What are the features of concentrated windings?

Ans. Cheap construction, maximum voltage for a given number of inductors. Concentrated windings have greater armature reaction and inductance than other types hence the terminal voltage of an alternator with concentrated winding



FIGS. 1,492 and 1,493.—Concentrated windings. A concentrated winding is one in which the armature has only *one tooth per phase per pole*, that is, the number of teeth equals the number of poles. A concentrated winding of the half coil type has only one side of a coil in each slot as in fig. 1,492. In the whole coil variety, each slot contains neighboring sides of adjacent coils, as in fig. 1,493. In construction, wedges are generally used for retaining the half coils, and with whole coils the teeth have projecting horns for this purpose

falls off more than with distributed winding when the current output is increased. An alternator, therefore, does not have as good regulation with concentrated winding as with distributed winding.

Ques. What should be noted with respect to concentrated windings?

Ans. A concentrated winding, though giving higher voltage

than the distributed type with no load, may give a lower voltage than the latter at full load.

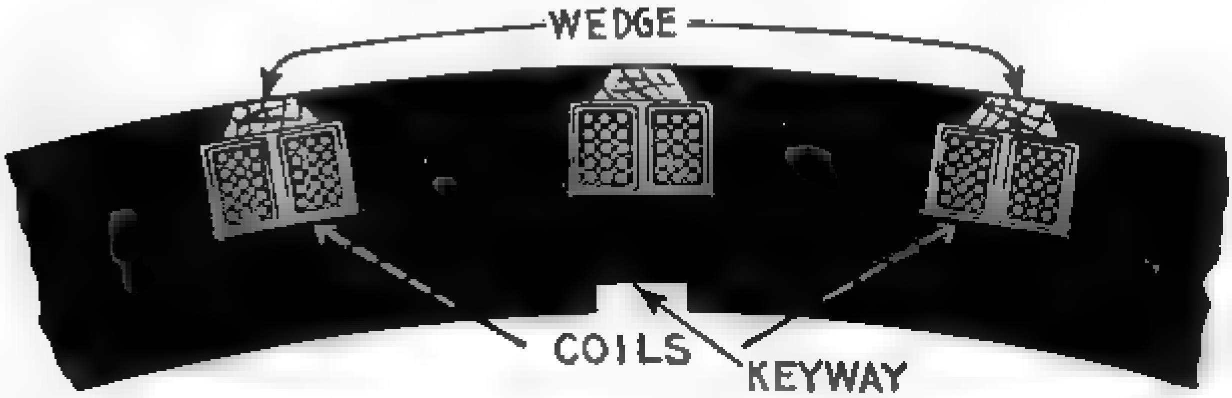


FIG. 1,494.—Laminated core with two coils in position; type of punchings used on some machines having concentrated whole coil windings. The manner of assembling the coils is shown in fig. 1,495.

Ques. What is the wave form with a concentrated winding?

Ans. The pressure curve rises suddenly in value as the armature slots pass under the pole pieces, and falls suddenly as the armature slots recede from under the pole pieces.

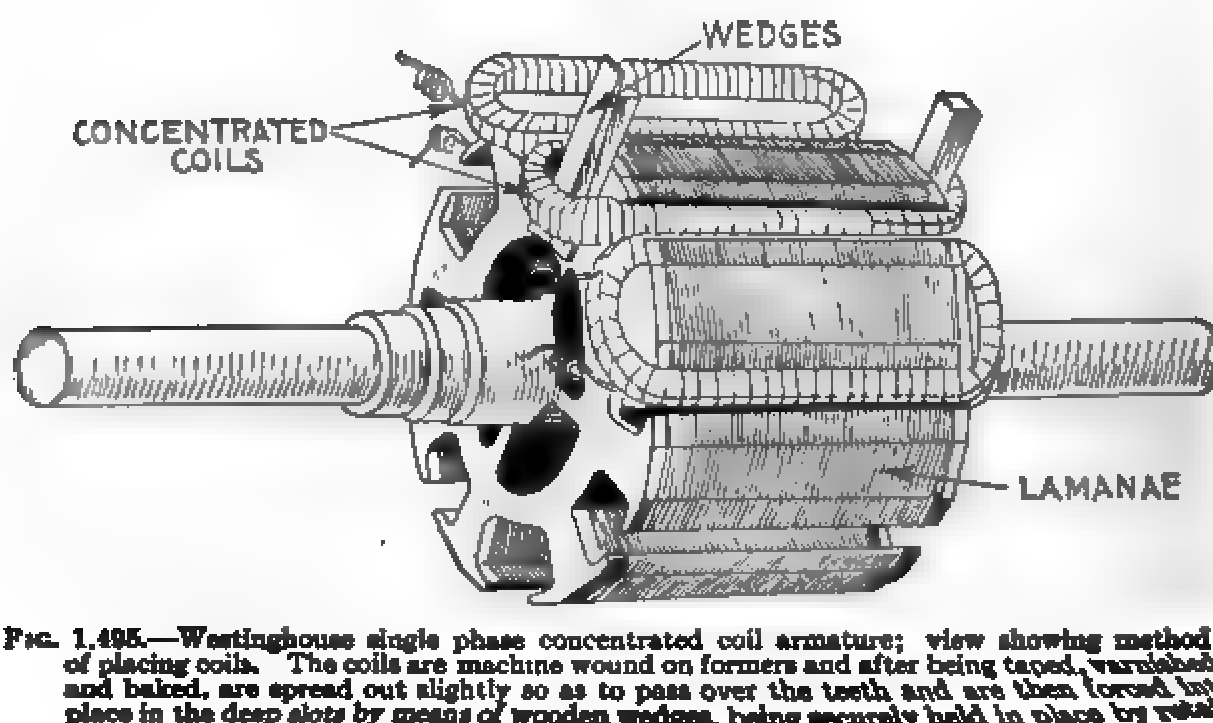
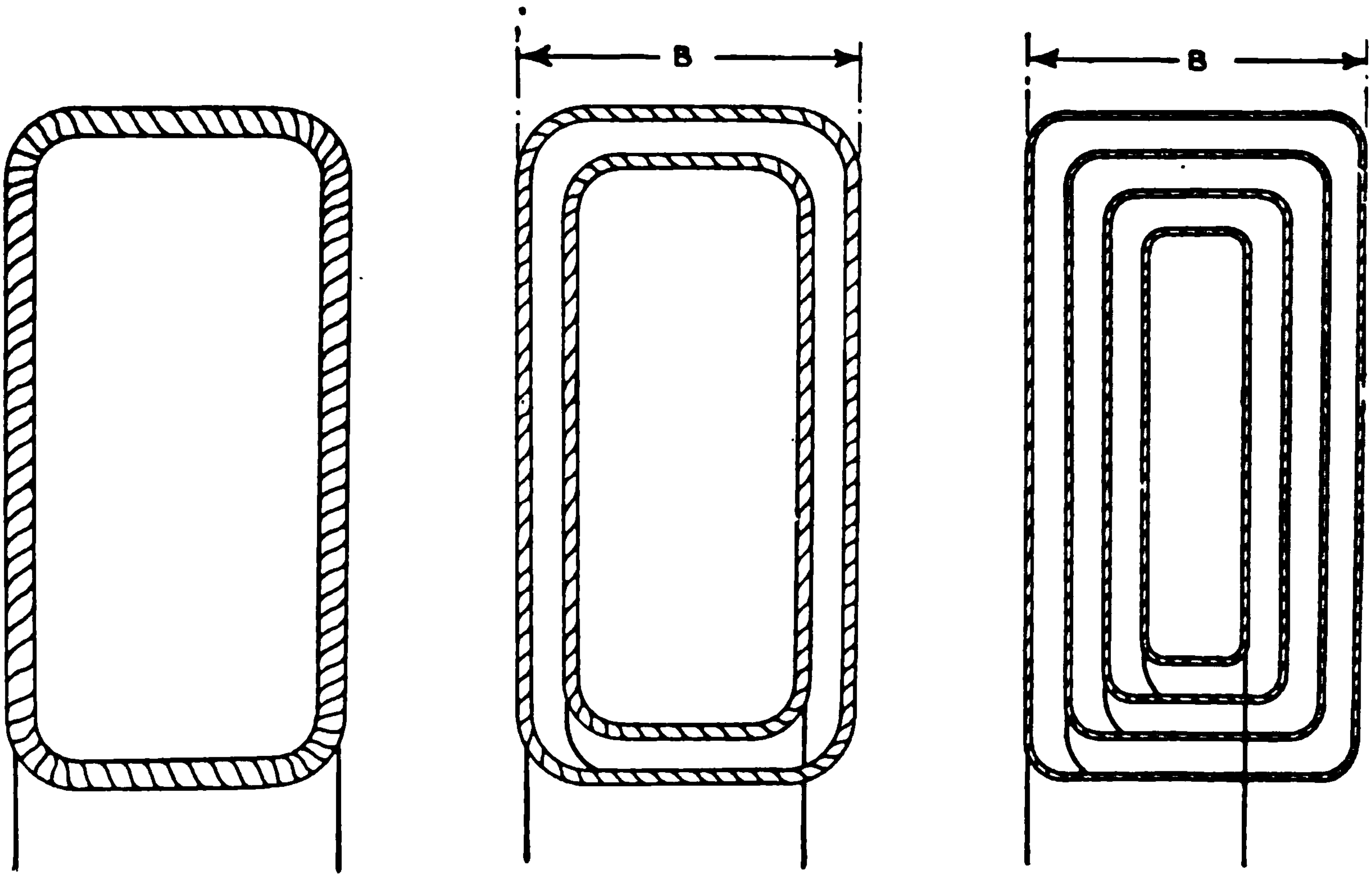


FIG. 1,495.—Westinghouse single phase concentrated coil armature; view showing method of placing coils. The coils are machine wound on formers and after being taped, varnished and baked, are spread out slightly so as to pass over the teeth and are then forced into place in the deep slots by means of wooden wedges, being securely held in place by retaining wedges, as shown in fig. 1,494.

Distributed or Multi-Coil Windings.—Instead of winding an armature so it will occupy only one slot per phase per pole, it may be spread out so as to fill *several slots per phase per pole.* This arrangement is called a distributed winding.

To illustrate, fig. 1,496 represents a coil of say fifteen turns. This could be placed on an armature just as it is, in which case only one slot would be required for each side, that is, two in all. In place of



CONCENTRATED COIL PARTIALLY DISTRIBUTED COIL FULLY DISTRIBUTED COIL

FIGS. 1,496 to 1,498.—Alternator coils, showing difference between the concentrated, partially distributed, and fully distributed forms. Fig. 1,496 shows a concentrated coil in which all the wire is wound in one large coil; in the partially distributed type fig. 1,497, the wire of fig. 1,496, is wound in two or more coils or "sections" connected as shown, leaving some space inside not taken up by the subdivisions. In fig. 1,498 the wire of fig. 1,496 is *fully distributed*, being wound in a series of coils, so that all the interior space is taken up by the wire, that is to say, the spaces not occupied by the wire (the teeth when placed on the armature) are of equal size.

this thick coil, the wire could be divided into several coils of a lesser number of turns each, arranged as in fig. 1,497; it is then said to be *partially distributed*, or it could be arranged as in fig. 1,498, when it is *said to be fully distributed.*

A partially distributed winding, then, is one, as in fig. 1,499, in which the coil slots do not occupy all the circumference of the armature; that is, the core teeth are not continuous.

A fully distributed winding is one in which the entire surface of the core is taken up with slots, as in fig. 1,500.

Ques. In a distributed coil what is understood by the breadth of the coil?

Ans. The distance between the two outer sides, as B in figs. 1,497 and 1,498.

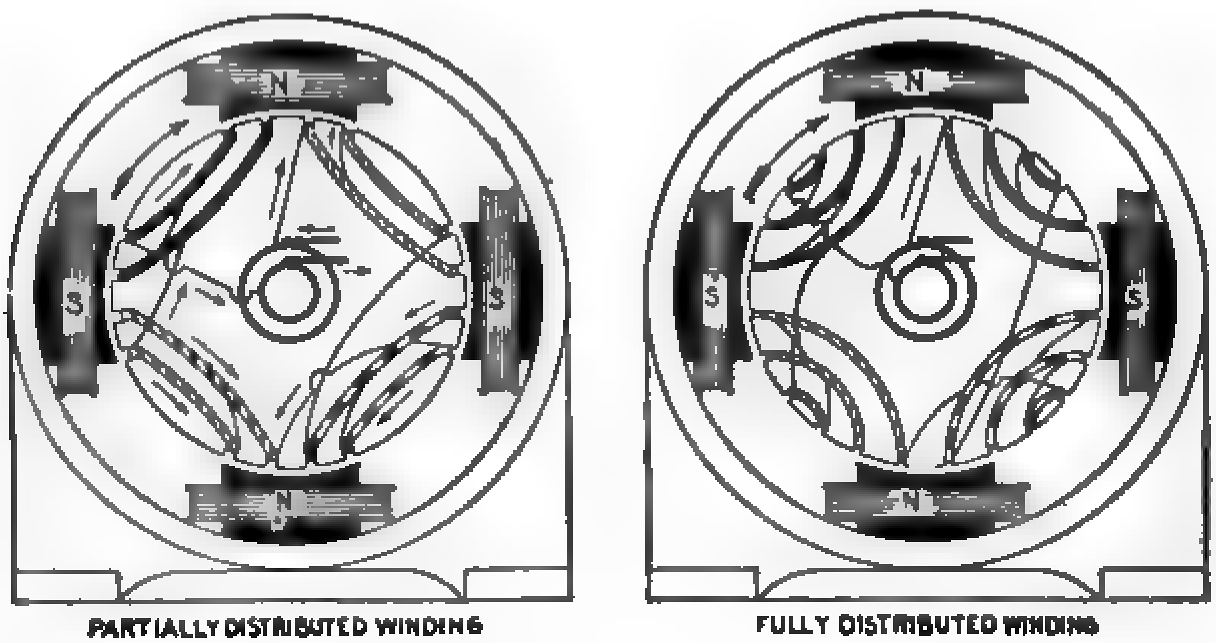


FIG. 1,499.—Partially distributed winding. Each coil unit is here divided into two concentric coils of different dimensions and connected in series, as shown in detail in fig. 1,497. This being a "whole coil" winding the several units are so connected that the winding of adjacent units proceeds in opposite directions, that is, one coil is wound clockwise, and the next counter clockwise, etc., so that the induced currents flow in a common direction as indicated by the arrows for the position shown.

FIG. 1,500.—Fully distributed winding. In this type of winding each coil consists of so many sub-coils that the winding occupies the entire surface of the armature core; that is, there are no extensive spaces unoccupied, the spacing being uniform as shown.

Ques. How far is it advisable to spread distributed coils of a single phase alternator?

Ans. There is not much advantage in reducing the interior

breadth much below that of the breadth of the pole faces, nor is there much advantage in making the exterior breadth greater than the pole pitch.

Undue spreading of distributed coils lowers the value of the Kapp coefficient (later explained) by reducing the breadth coefficient and makes necessary a larger number of inductors to obtain the same voltage.

The increase in the number of inductors causes more armature self-induction. From this point of view, it would be preferable to concentrate the winding in fewer slots that were closer together. This, however, would accentuate the distorting and demagnetizing reactions of the

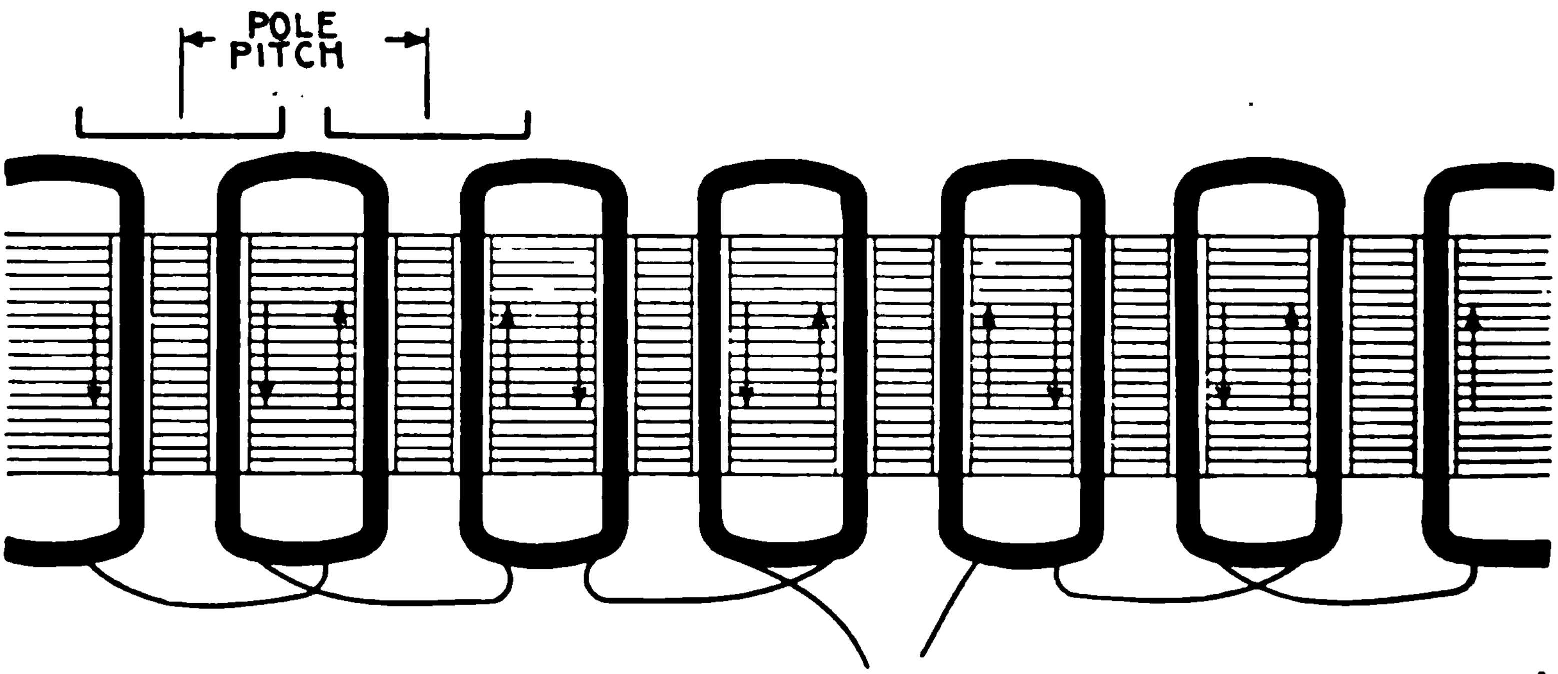


FIG. 1,501.—Developed diagram of single phase concentrated whole coil winding in two slot stamping for six pole alternator. If the sides of adjacent whole coils be slightly separated by placing the winding in a two slot stamping the electrical result will not differ materially from the monotooth whole coil winding, but if the winding be hemitropic, as in fig. 1,502, and has coils of two sizes as shown, it will be suitable for high voltages.

armature. Accordingly, between these two disadvantages a compromise is made, as to the extent of distributing the coils and spacing of the teeth, the proportions assigned being those which experience shows best suited to the conditions of operation for which the machine is designed.

The Kapp Coefficient.—A volt or unit of electric pressure is defined as the pressure induced by the cutting of 100,000,000 or 10^8 lines of force per second. In the operation of an alternator the maximum pressure generated may be expressed by the *following* equation:

$$E_{max} = \frac{\pi f Z N}{10^8} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which

f = frequency;
Z = number of inductors in series in any one magnetic circuit;
N = magnetic flux, or total number of magnetic lines in one pole or in one magnetic circuit.

The maximum value of the pressure, as expressed in equation (1), occurs when $\theta = 90°$.

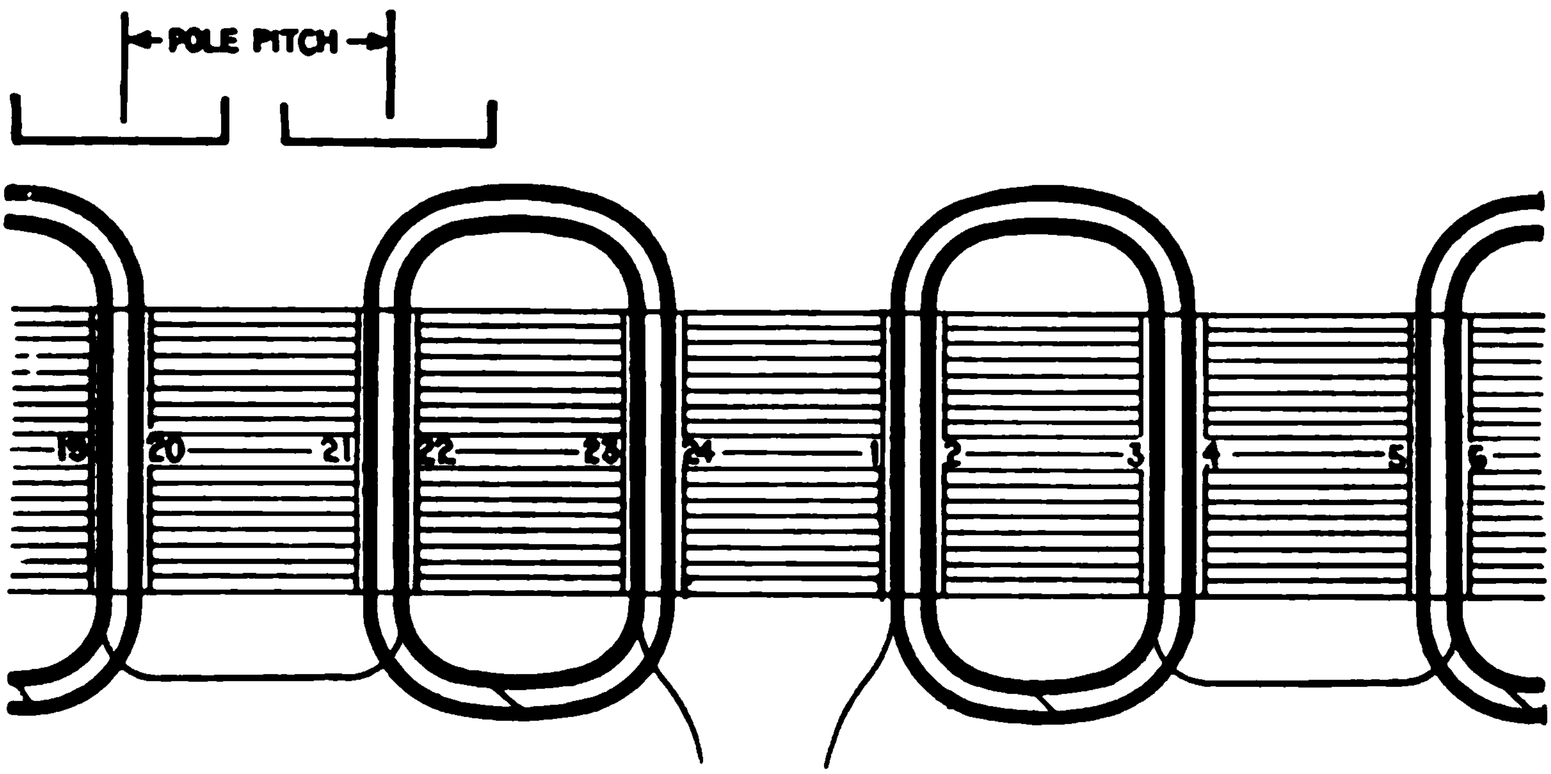


Fig. 1,502.—Developed diagram of single phase partially distributed half coil winding for six pole alternator in two slot stamping, same as in fig. 1,501. In this arrangement the direction of rotation is not reversed. It is a question as to how far the coils of a single-phase armature may be spread with advantage. There is not much advantage in reducing the interior breadth of the coils below that of the pole face, nor in widening the exterior breadth beyond that of the pole pitch.

The virtual value of the volts is equal to the maximum value divided by $\sqrt{2}$, or multiplied by $\frac{1}{2}\sqrt{2}$, hence,

$$E_{virt} = \frac{\frac{1}{2}\sqrt{2} \times \pi f Z N}{10^8} = \frac{2.22 f Z N}{10^8} \ldots\ldots\ldots\ldots (2)$$

This is usually taken as the fundamental equation in designing alternators. It is, however, deduced on the assumptions that

[redacted]

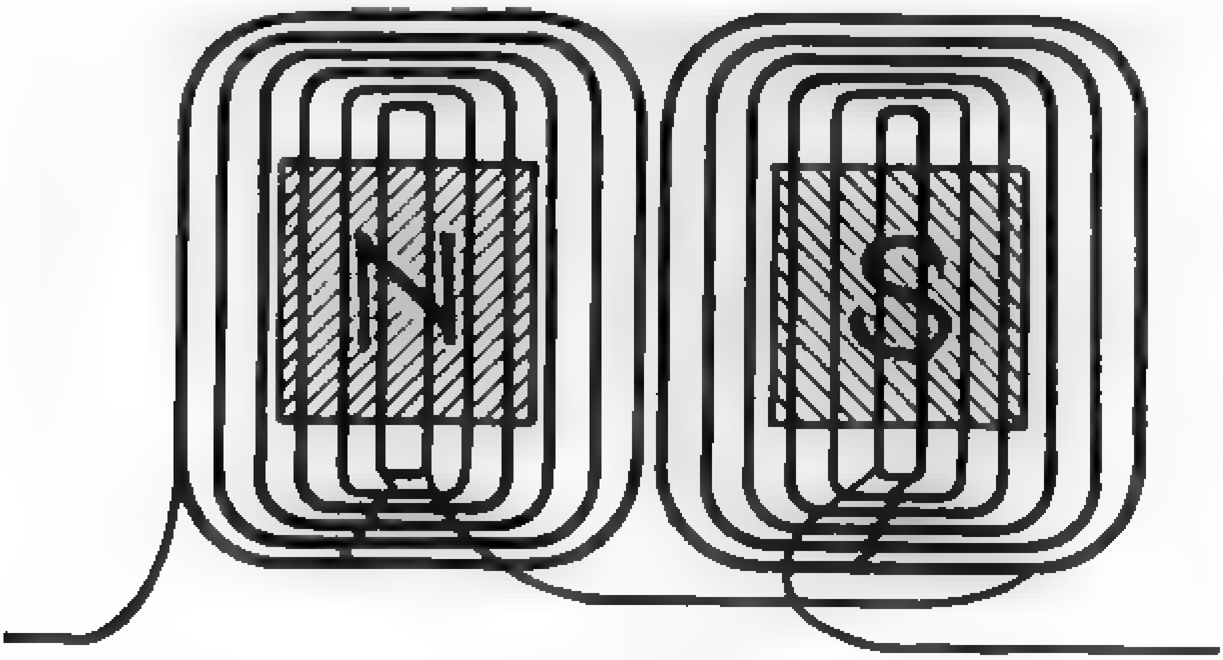


FIG. 1,503.—Developed diagram of single phase winding with fully distributed coils. As explained, excessive spreading lowers the value of the "Kapp" coefficient, and consequently the voltage; also the use of a larger number of inductors to obtain the same voltage results in an increase of armature self-induction. On the other hand, if the winding were concentrated in fewer slots and these slots were closer together, the result will be an increase in distorting and demagnetizing reactions of the armature. Therefore, a compromise between these two disadvantages must be made. The common practice is to wind in two or three slots per pole per phase.

FIG. 1,504.—Allis-Chalmers lap wound coils forming a three slot distributed coil unit. In construction, after the coils have been covered with insulating materials and treated with insulating compound, the parts that lie in the slots are pressed to exact size in steam-heated moulds. This runs the insulating material into all the small spaces in the coil, excluding moisture and rendering the insulation firm and solid. The ends of the coils, where they project beyond the slots, are heavily taped.

the distribution of the magnetic flux follows a sine law, and that the whole of the loops of active inductors in the armature circuit acts simultaneously, that is to say, the winding is concentrated.

In practice, the coils are often more or less distributed, that is, they do not always subtend an exact pole pitch; moreover, the flux distribution, which depends on the shaping and breadth

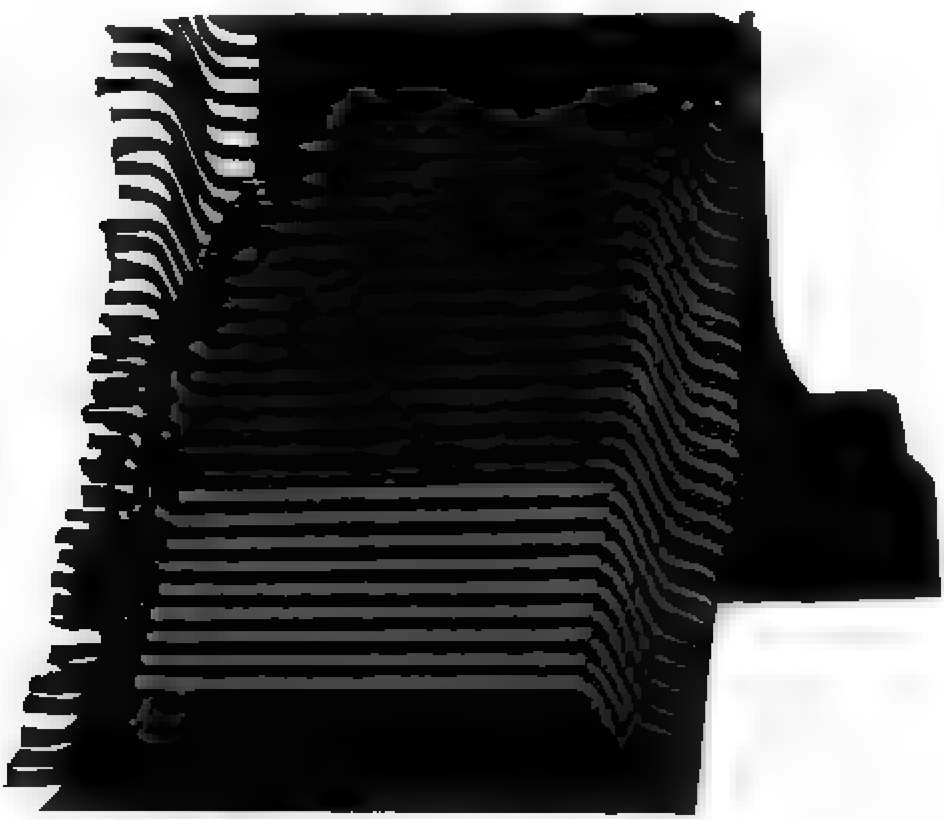
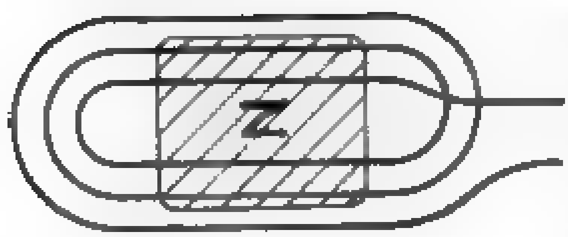
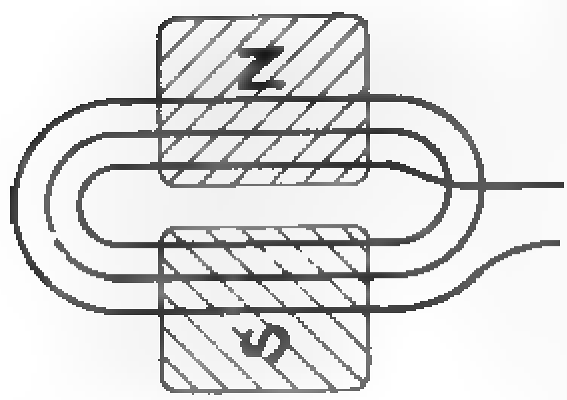


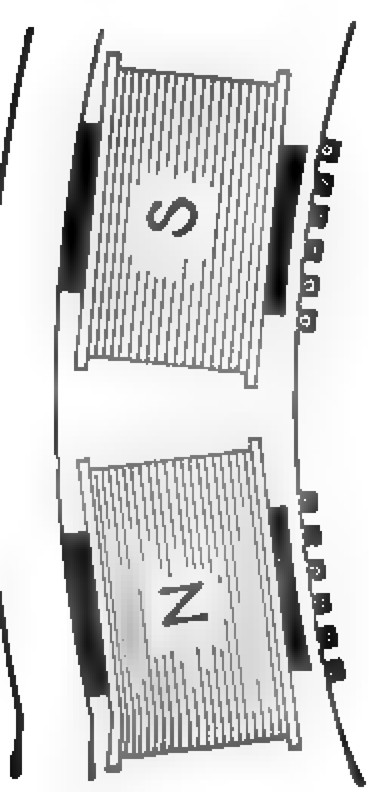
FIG. 1606.—Allis-Chalmers armature construction; view showing section of frame and two layer winding.

of the poles, is often quite different from a sine distribution. Hence, the coefficient 2.22 in equation (2) is often departed from, and in the general case equation (2) may be written

$$E_{virt} = \frac{kfZN}{10^8} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$







FIGS. 1,506 and 1,507.—Effect of breadth of coils in distributed windings. In the section of the alternator shown in fig. 1,506 the directions of the pressures induced as the armature rotates clockwise are represented by dots for those which act towards the reader, and by crosses for those which act from the reader (the dots and crosses representing respectively the heads and tails of arrows). Since the field is not uniform but maximum at the center and gradually weakening towards the extremities, it is obvious that the maximum pressure is induced in any inductor as it passes the center of the pole, this variation being indicated by the heavier dots and crosses toward the center. Now if a number of these inductors be connected up to form a distributed coil as in fig. 1,507, the pressures induced in each will be added, but all the maximum pressure will not be induced in all at the same time, hence the total pressure induced in the distributed coil is less than it would be if the coil were concentrated as in fig. 1,509.

FIG. 1,508.—Diagram of distributed coil whose inner breadth is less than the breadth of the pole face, showing the disadvantage of such arrangement. The pressures induced in the inner windings of such a coil are opposing each other at the instant depicted, that is, while the inductors are under the pole face, such action of course being objectionable.

where k is a number which may have different values, according to the construction of the alternator. This number k is called the *Kapp coefficient* because its significance was first pointed out by Prof. Gisbert Kapp.

The value of k is further influenced by a "breadth coefficient" or "winding factor."

The effect of breadth in distributed windings is illustrated in figs. **1,506** to **1,508**.

Wire, Strap, and Bar Windings.—In the construction of alternators, the windings may be of either wire, strap, or bar, according to which is best suited for the conditions to be met.

Ques. What conditions principally govern the type of inductor?

Ans. It depends chiefly upon the current to be carried and the space in which the inductor is to be placed.

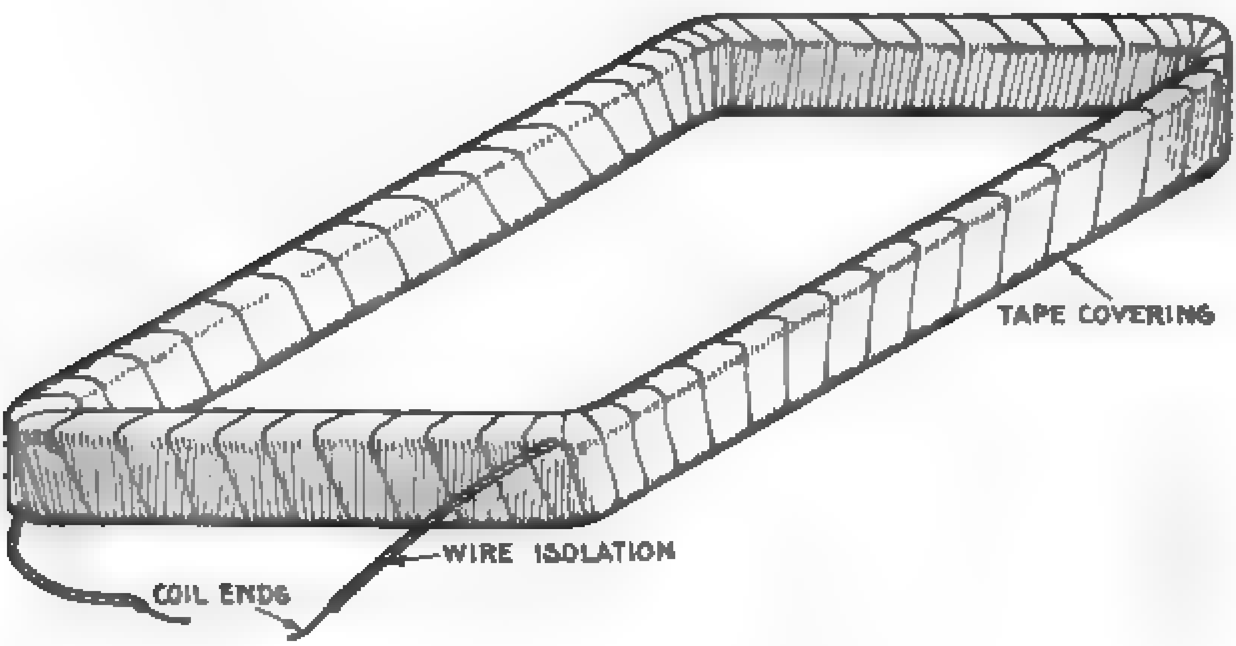


FIG. 1,509.—Simple form of alternator coil, consisting of numerous turns of insulated wire wound around a form, then covered with a tape winding, varnished and baked.

Ques. What kind of inductors are used on machines intended for high voltage and moderate current?

Ans. The winding is composed of what is called *magnet wire*, with double or triple cotton insulation.

Ques. Where considerable cross section is required how is a wire inductor arranged?

Ans. In order that the coil may be flexible several small wires in multiple are used instead of a single large wire.

Ques. How is the insulation arranged on inductors of this kind?

Ans. Bare wire is used for the wires in parallel, insulation being wrapped around them as in fig. 1,510.

This construction reduces the space occupied by the wires, and the insulation serves to hold them in place.

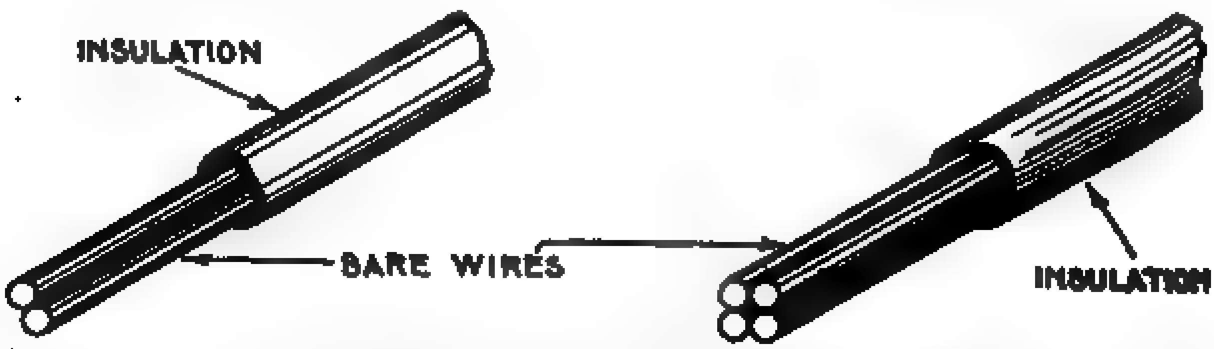


FIG. 1,510 and 1,511.—Multi-wire inductors. When the cross section of inductor necessary to carry the current is large, the use of a single wire would present difficulties in winding, on account of its stiffness. Accordingly two or more smaller wires are used in parallel to secure the required cross section. Bare wire is used and the several sections encased in insulation as shown, the combination being more flexible than an equivalent single wire

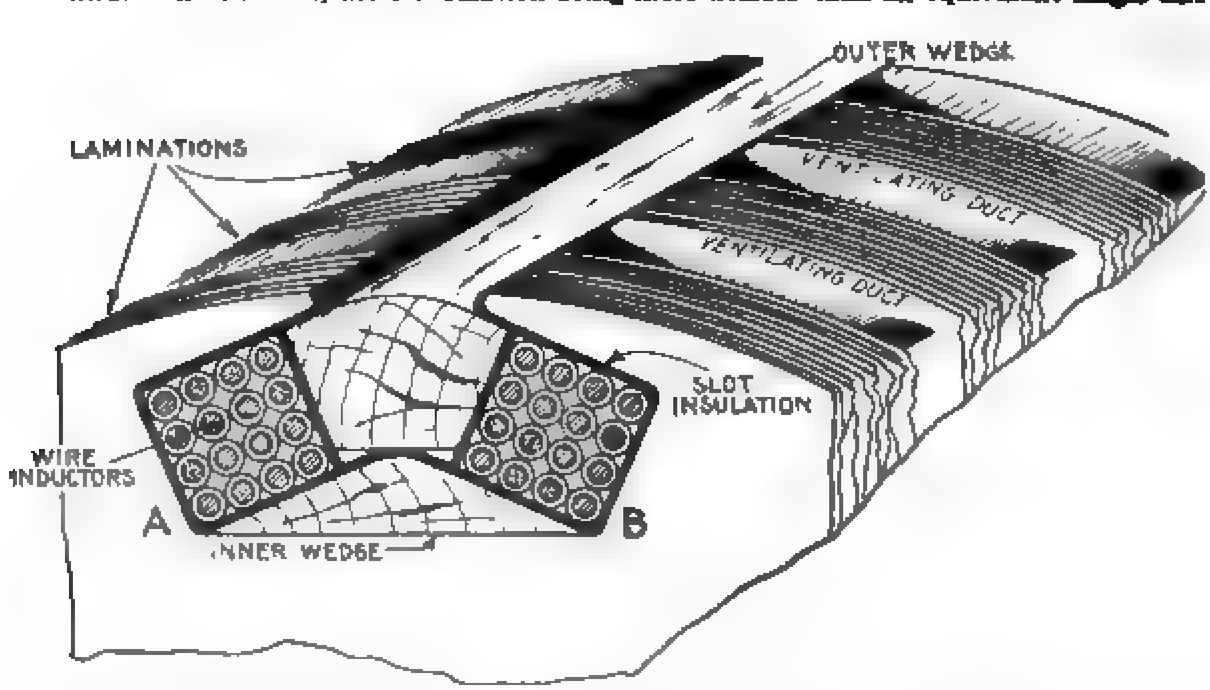


FIG. 1,512.—Two coil slot for whole coil winding. The slot has two recesses A and B for the reception of separate coils. In assembling the winding, the inner wedge is first placed in position and then the slot line with the insulating material. This usually consists of alternate layers of mica and pressboard. The coils composed of several turns of wire *or copper* strip are wound in place, and after covering with a layer of insulation, the outer *wedge is pushed in* place to retain the inductors in position.

Ques. What precaution is taken in insulating a wire wound coil containing a large number of turns?

Ans. On account of the considerable difference of pressure between layers, it is necessary to insulate each layer of turns as well as the outside of the coil, as shown in fig. 1,513.

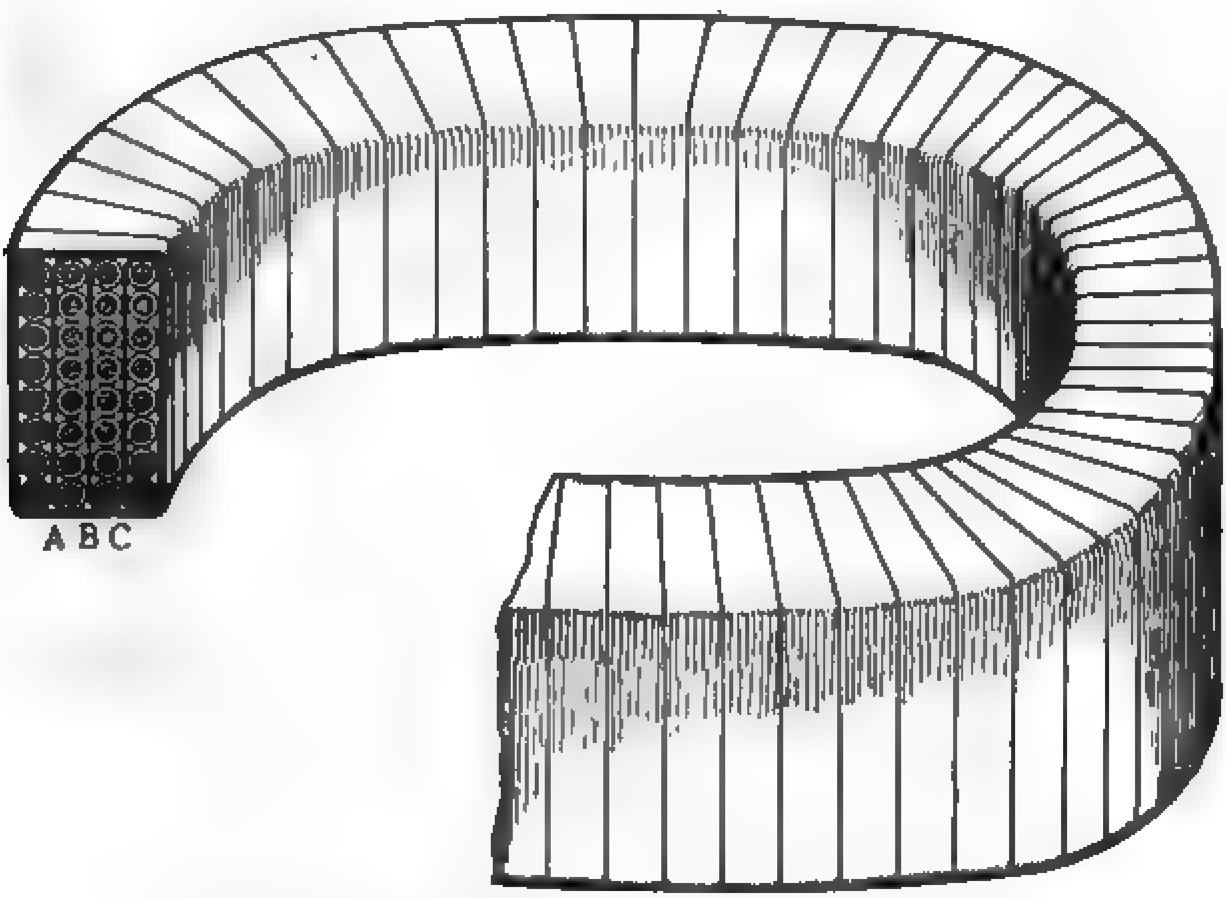


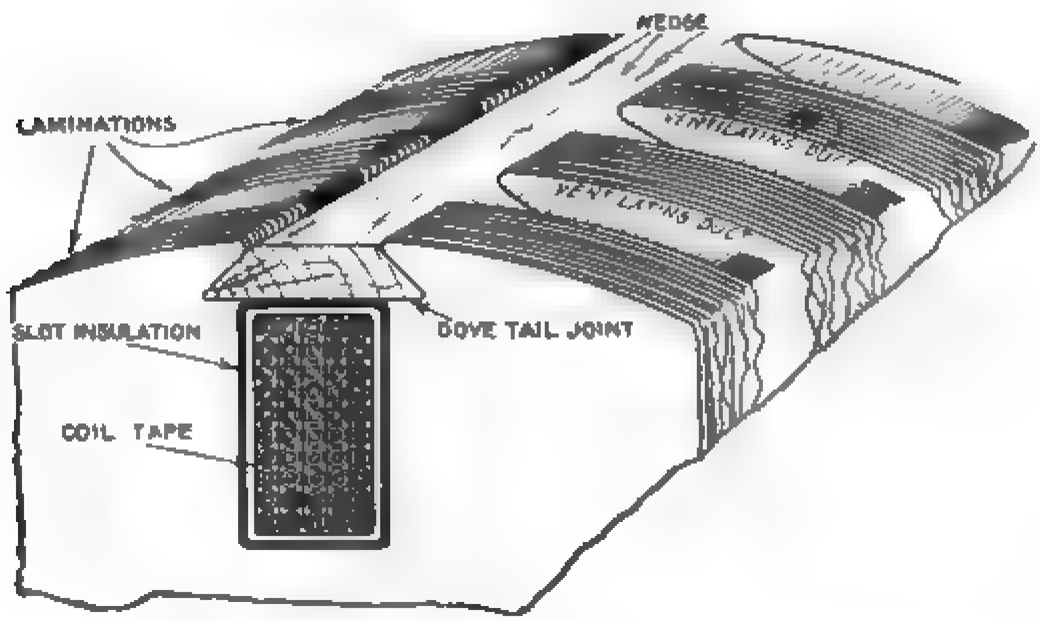
FIG. 1,513.—Method of winding a coil containing a large number of turns, when there is considerable difference of pressure between the layers. In such cases to guard against short circuits or breakdown of the insulation, each layer of turns is insulated from the next layer by the insulating strips A, B, C, in addition to the regular insulation around each wire. After the coil is made up it is wound with insulating tape, varnished and baked.

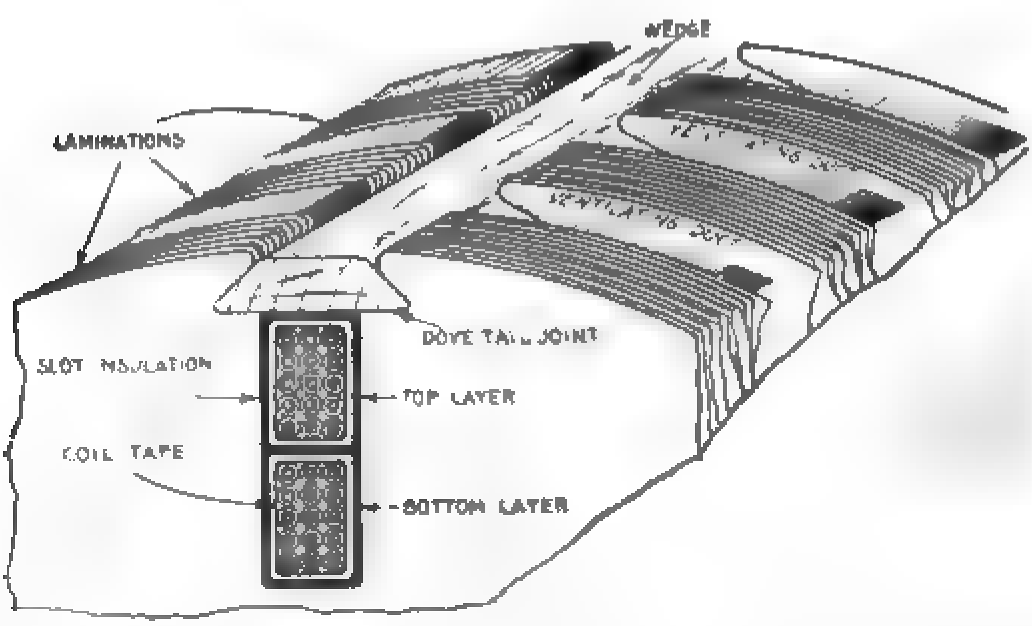
Ques. Do distributed coils require insulation between the separate layers?

Ans. Since they are sub-divided into several coils insulation between layers is *usually not* necessary.

Ques. How is a coil covered?

Ans. It is wound with a more or less heavy wrapping of tape depending upon the voltage.



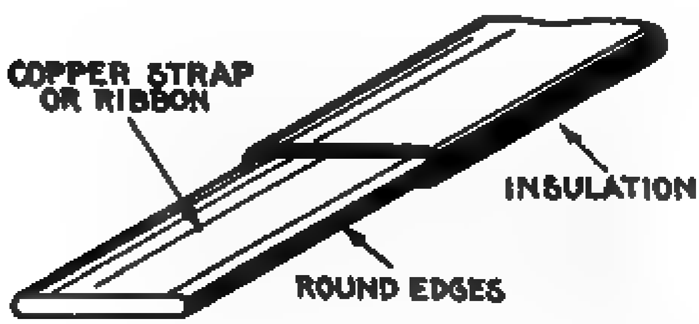


FIGS. 1,514 and 1,515.—Single and double layer multi-wire inductors and methods of placing them on the core. Here the term layer means unit, in fact each unit is made up of several "layers" of wires. In fig. 1,514, where so many wires are bunched together in one unit, each layer of turns is separated from those adjacent by insulating strips on account of the *considerable* difference of pressure between layers. This insulation is not necessary in fig. *1,515 where there* are two units or so called layers. In both cases the inductors are held *in place by wedges* driven into dovetail grooves.

Linen tape of good quality, treated with linseed oil, forms a desirable covering. Where extra high insulation is required the tape may be interleaved with sheet mica.

Ques. Is the insulation placed around the coils all that is necessary?

Ans. The slots into which the coils are placed, are also insulated.



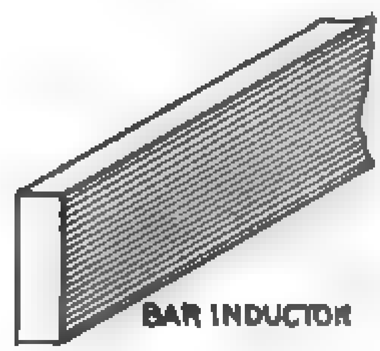


FIG. 1,516.—Copper strap or ribbon with insulation. These are generally from $\frac{1}{16}$ to $\frac{1}{8}$ inch thick with rounded edges as shown to avoid cutting the insulation.

FIG. 1,517.—Bar inductor. Its shape enables putting the maximum cross section of copper into the slot and is used to advantage on machines which generate large currents.

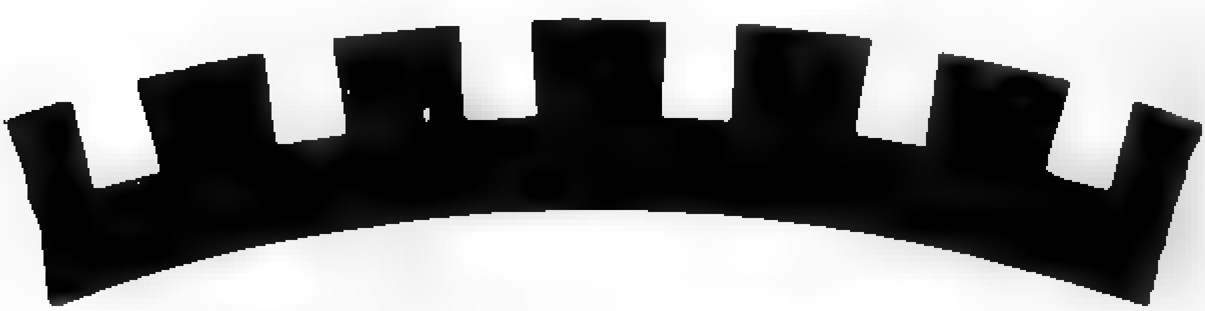
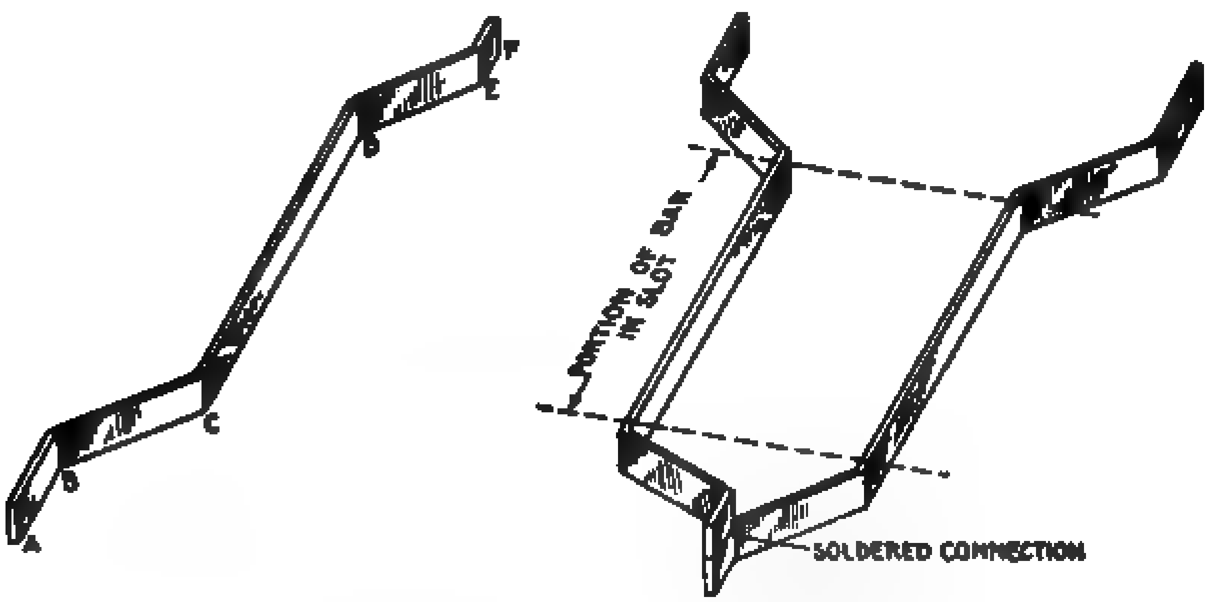


FIG. 1,518.—Style of armature core stamping used with bar wound machines. This construction, since there are no indentations in the teeth for wedges, makes it necessary to provide bands to hold the bars in place.

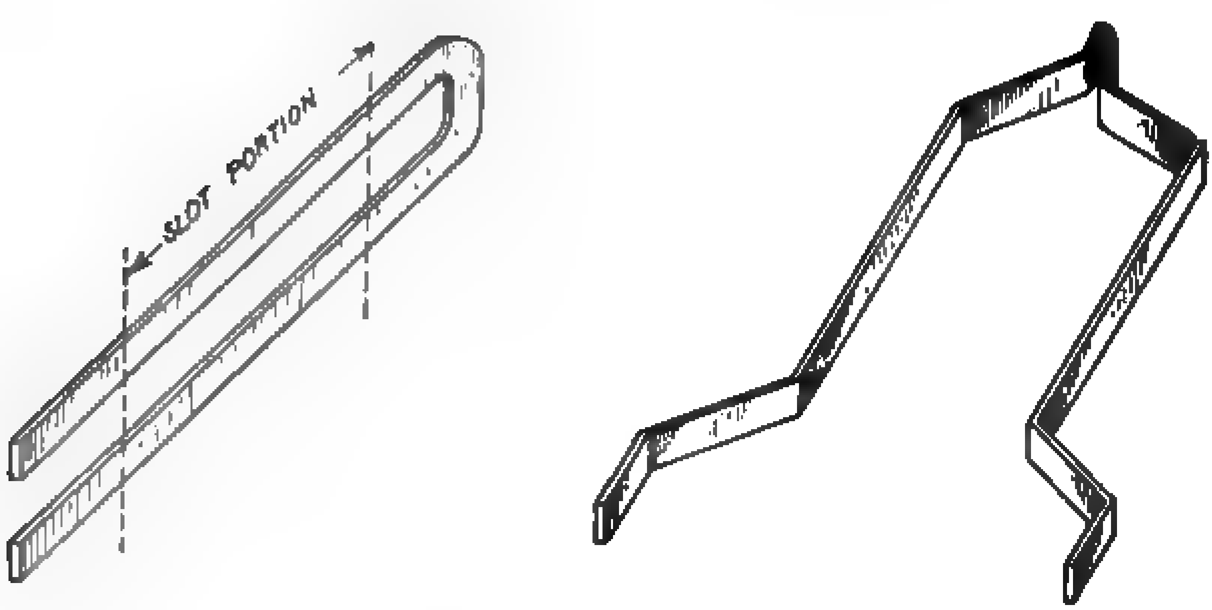
Ques. How are bar windings sometimes arranged?

Ans. In two ***layers, as in*** **fig. 1,523.**

Single and Multi-Slot Windings.—These classifications correspond to *concentrated* and *distributed windings*, previously described. In usual modern practice, only two-thirds of the total number of slots (assuming the spacing to be uniform)



FIGS. 1,519 and 1,520.—Bent bar inductor and method of connection with soldered joint. Fig. 1,519 shows one bar and shape of bent ends. The portion from C to D is placed in the slot; B to C and D to E, bent or connector sections; A to B and E to F, ends bent parallel to slot for soldering. Fig. 1,520 shows two bar inductors connected.



FIGS. 1,521 and 1,522.—Method of avoiding a soldered joint at one end of a bar inductor by using a bar of twice the length shown in fig. 1,519, and bending it into a long U form, as in fig. 1,521, after which it is spread out forming two inductors, as in fig. 1,522.

of a single phase armature are wound with coils. The reason for this may be explained by aid of fig. 1,524, which shows an armature with six slots per pole, four of which are wound. Owing to the different positions of, say, coils A and B, there will be a difference in phase between the pressure generated in them and consequently the resultant pressure of the two coils joined in series will be less than the sum of the pressure in each coil.

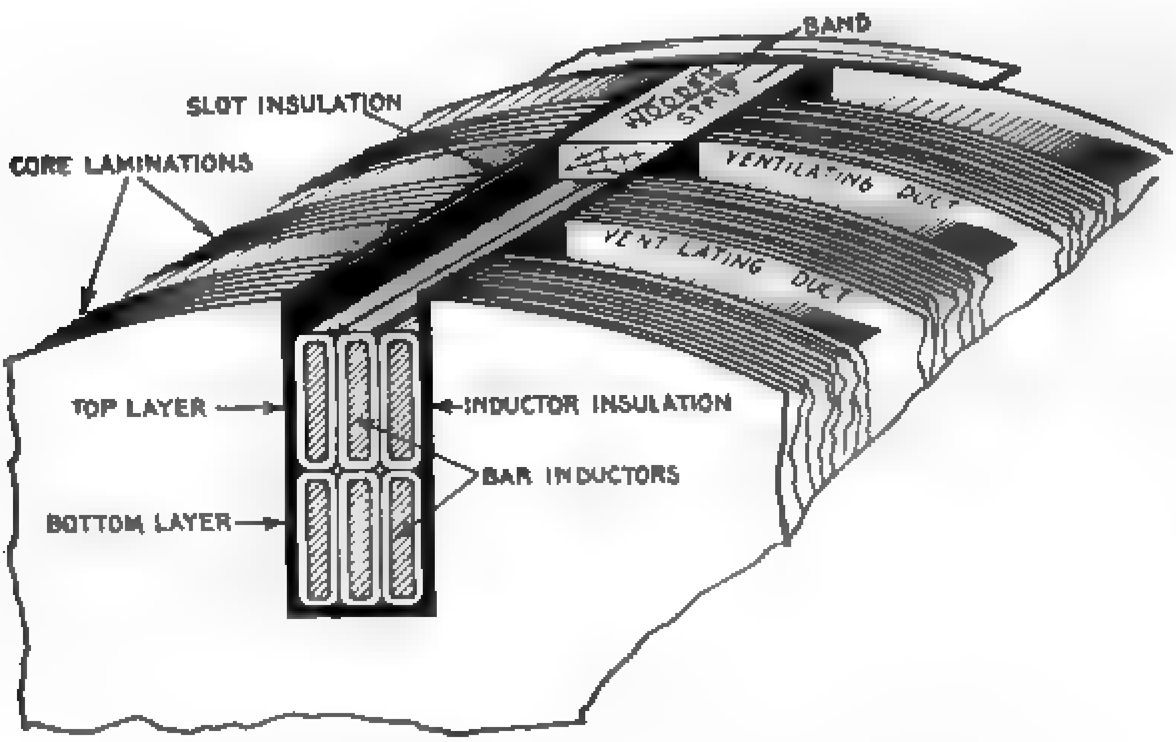


FIG. 1,523.—Arrangement in slot of two layer bar winding. With bar inductors, as must be evident from the illustration, the maximum cross section of copper can be placed in a slot of given dimension, hence a bar winding is used to advantage for alternators designed to carry a large current. Bar inductors, on account of the shape of their ends, must be placed in the slots from the top, because the bent ends do not admit of pushing them in. Straight slots are therefore necessary, the inductors being held in place by wooden strips and tie bands as shown.

Fig. 1,525 shows the pressure plotted out as vector quantities, and the table which follows gives the relative effectiveness of windings with various numbers of slot wound in series.

The figures in the last column of the table show that a large *increase in the weight* of active material is required if the

inductors in a single phase machine are to be distributed over more than two-thirds the pole pitch. Again, if much less than two-thirds of the surface be wound, it is more difficult to provide a sine wave of pressure.

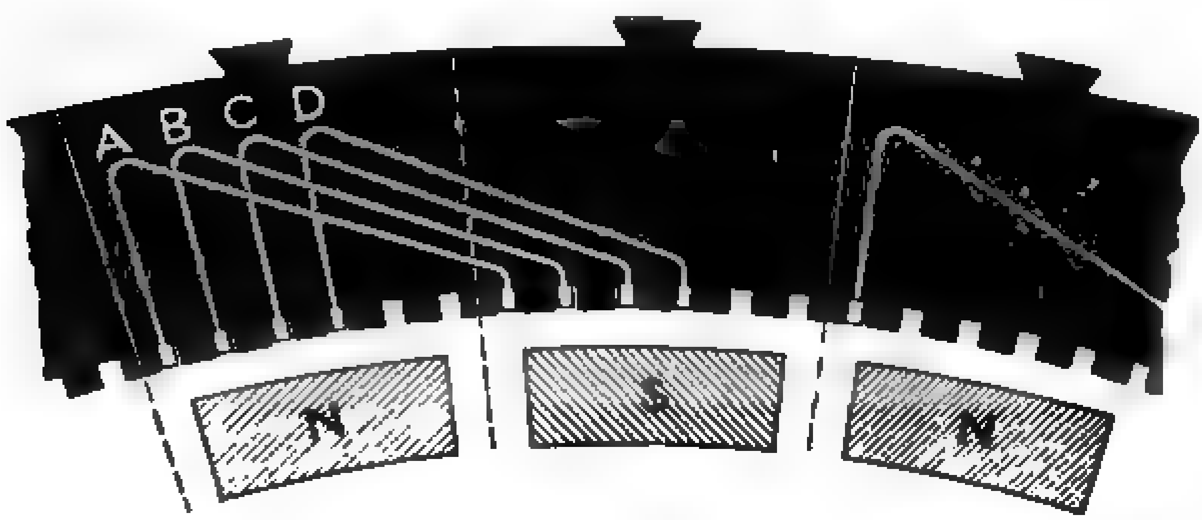


FIG. 1,524.—Diagram of single phase multi-coil or distributed winding to show characteristic differences in action and construction from single coil or concentrated winding.

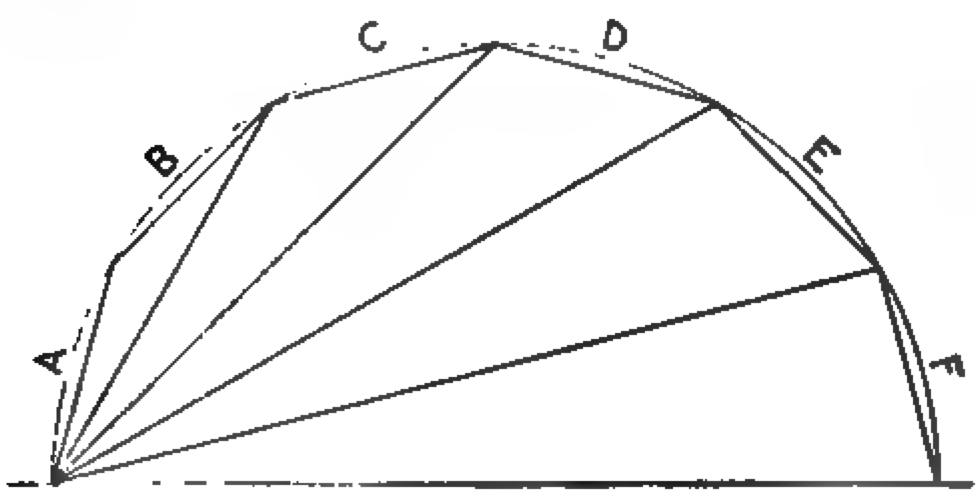


FIG. 1,525.—Vector diagram of pressures induced in the single phase multi-coil or distributed winding shown in diagram in fig. 1,524.

TABLE OF RELATIVE EFFECTIVENESS OF WINDINGS

Slots wound in series	Pressure across coils	Winding coefficient	Quantity of copper to produce same pressure
1	1	1	1
2	1.93	.97	1.03
3	2.73	.91	1.10
4	3.34	.84	1.19
5	3.72	.74	1.35
6	3.86	.64	1.56

Ques. What other advantage besides obtaining a sine wave is secured by distributing a coil?

Ans. There is less heating because of the better ventilation.

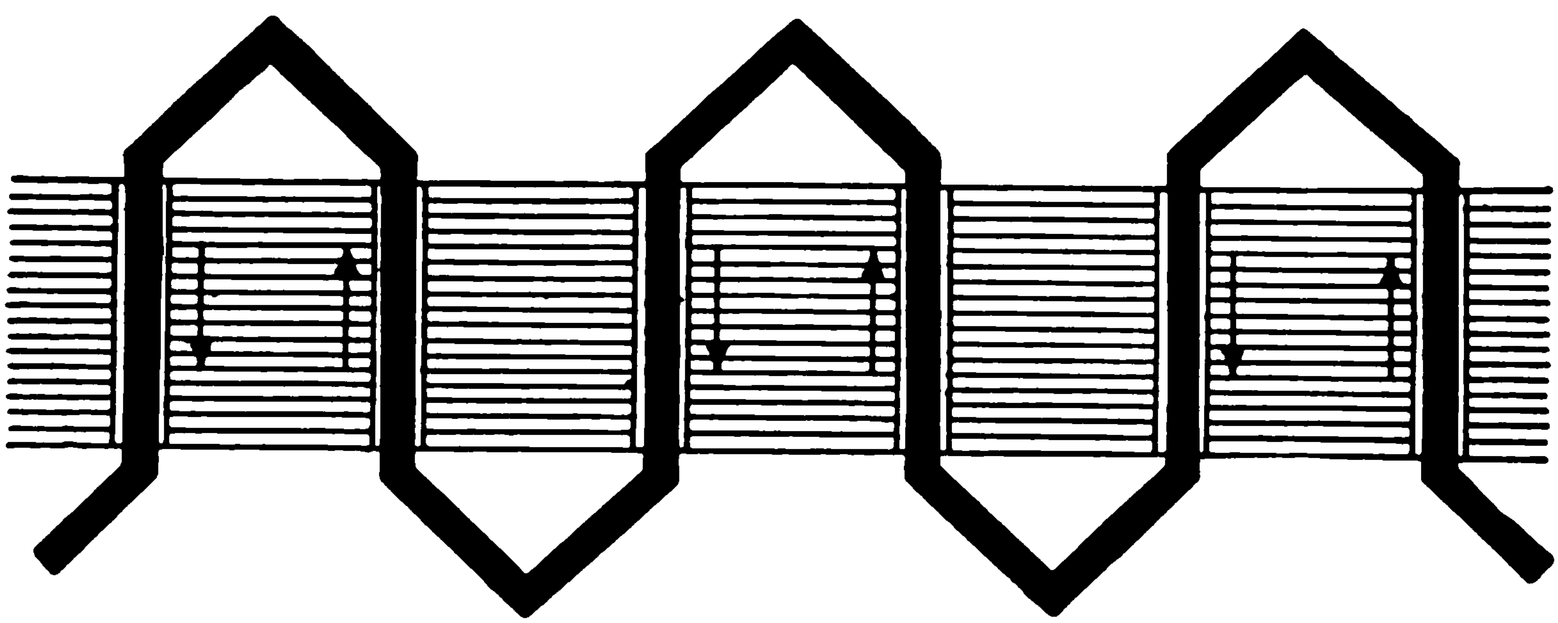


FIG. 1,526.—Developed diagram of a single phase monotooth or one slot bar winding; it is suitable only for operation at low voltage.

Single Phase Windings.—There are various kinds of single phase winding, such as, concentrated, distributed, hemitropic, etc. Fig. 1,527 shows the simple type of single phase winding. It is a "one slot" winding, that is, concentrated coils are used.

The armature has the same number of teeth as there are poles, the concentrated coils being arranged as shown. In designing

such a winding, the machine, for example, may be required to generate, say, 3,000 volts, frequency 45, revolutions 900 per minute.

These conditions require 720 inductors in series in the armature circuit, and as the armature is divided into six slots corresponding to the six poles, there will be 120 inductors per slot, and the coil surrounding

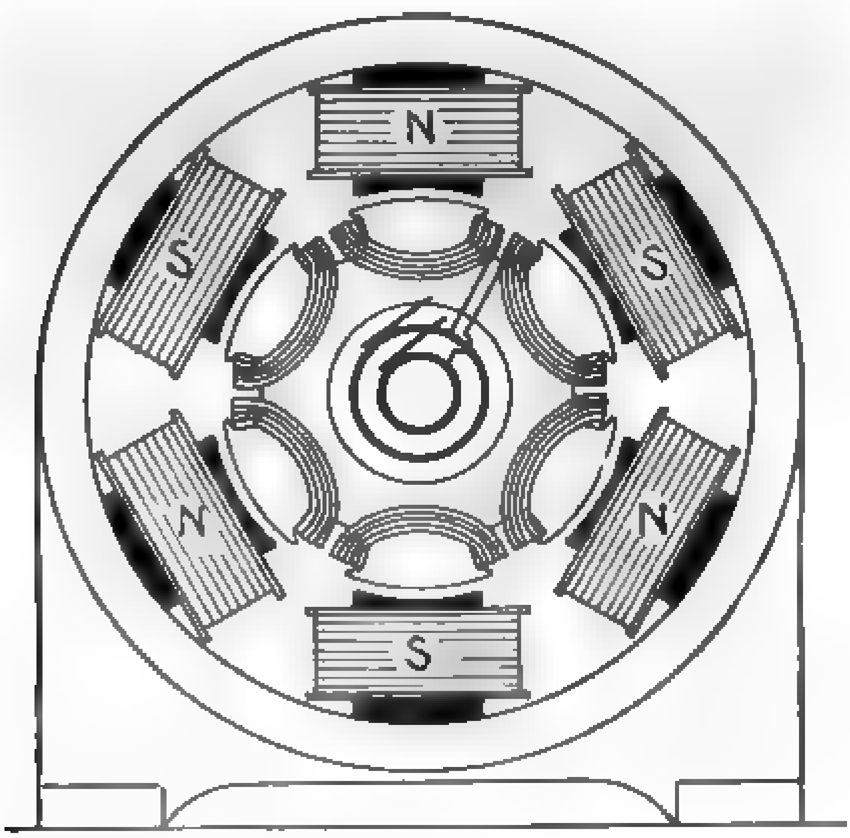


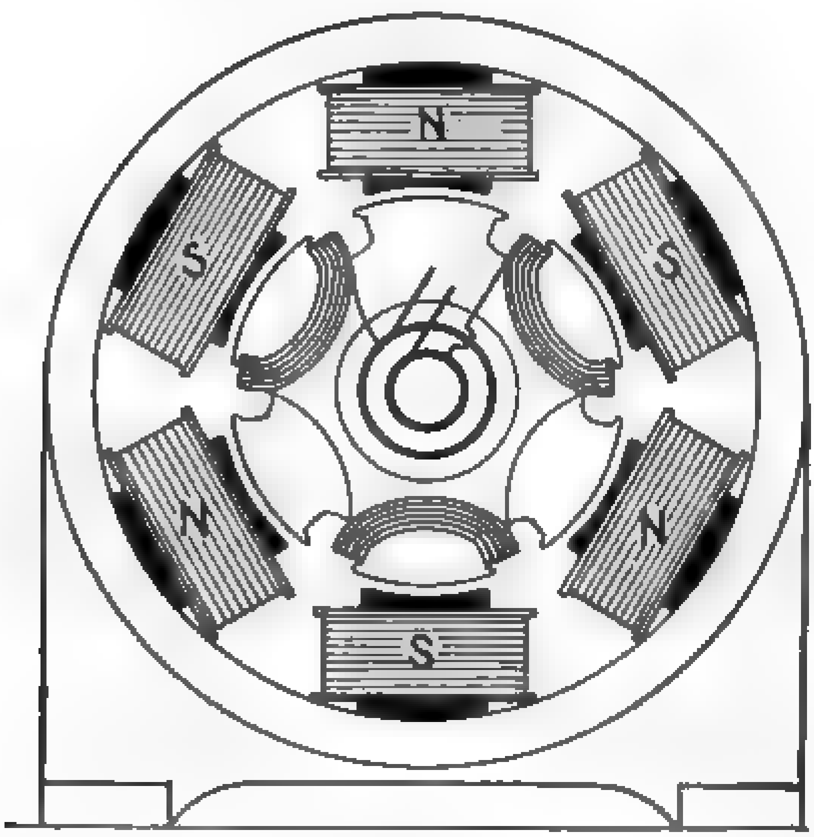
FIG. 1,527.—Diagram of six pole single phase revolving armature alternator, with monotooth or concentrated whole coil winding. For 3,000 volts at 900 revolutions per minute, 120 inductors are required. And in the case of a concentrated or monotooth winding they may be arranged in "whole coils" as above or in "half coils" (hemitropic) as in fig. 1,528.

each of the six teeth on the surface of the armature will consists of 60 turns. The connections must be such as to give alternate clockwise and counter-clockwise winding proceeding around the armature.

Ques. In what other way could the inductors be *arranged in* concentrated coils?

Ans. They could be grouped in three coils of 120 turns each, shown in fig. 1,528.

When thus grouped the arrangement is called a hemitropic winding, as previously explained.



1,528.—Diagram of six pole single phase alternator with concentrated half coil or hemitropic winding of same capacity as in fig. 1,527. There are an equal number of inductors, but in this case arranged in three instead of six coils. In this winding the direction of winding is alternately reversed so that the induced pressures do not oppose one another.

Ques. What is the advantage, if any, of a half coil nding?

Ans. In single phase machines a half coil winding is equiva- t, electrically, to a monotooth winding, and, therefore, is not any particular advantage; but in three phase machines, it has lecided advantage, as in such, a concentrated winding yields igher pressure than a distributed winding.

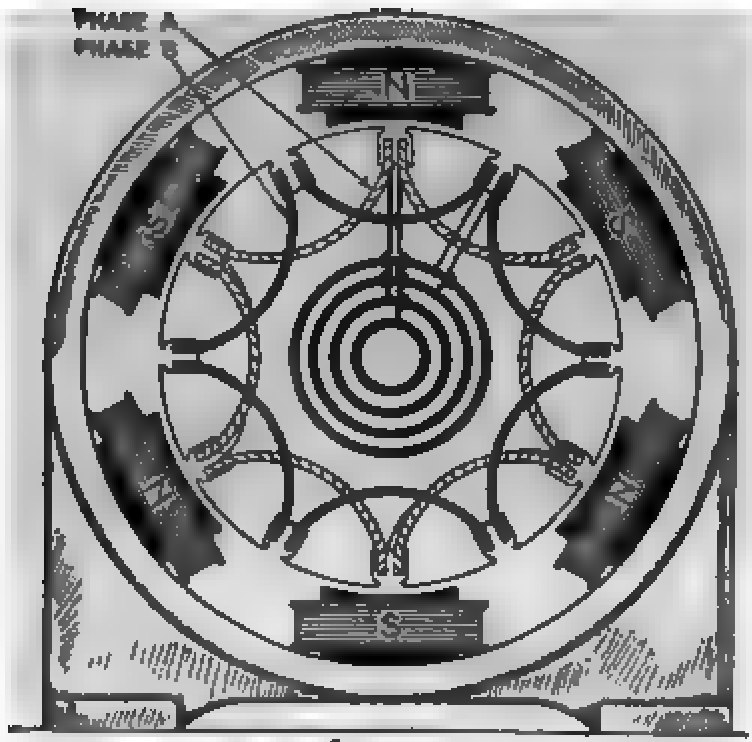


FIG. 1,529.—Two phase concentrated whole coil winding. In this style winding the total number of slots is twice the number of poles, or one slot per pole per phase. It comprises two windings identical with fig. 1,527, being spaced 90 polar degrees as shown. The two circuits are independent, the windings terminating at the four collector rings.

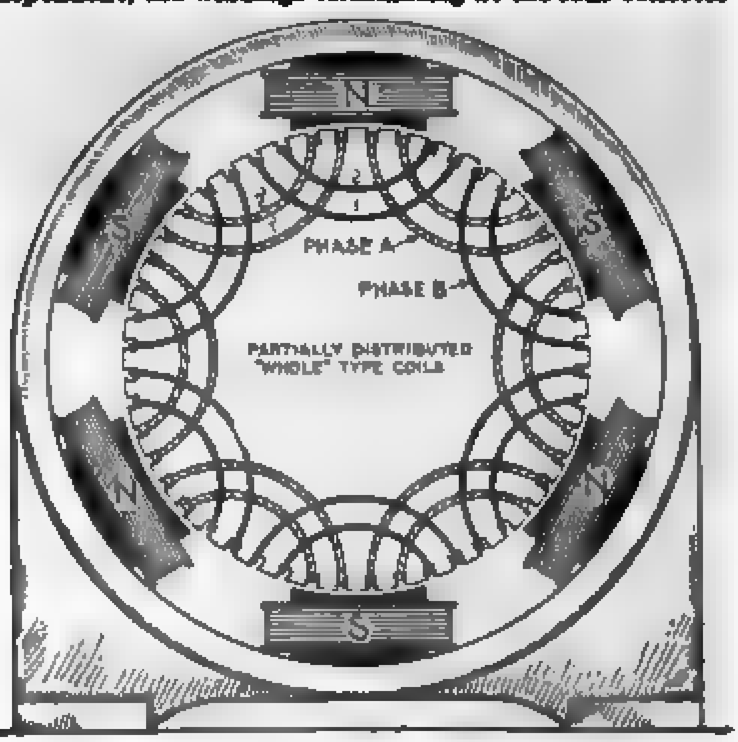
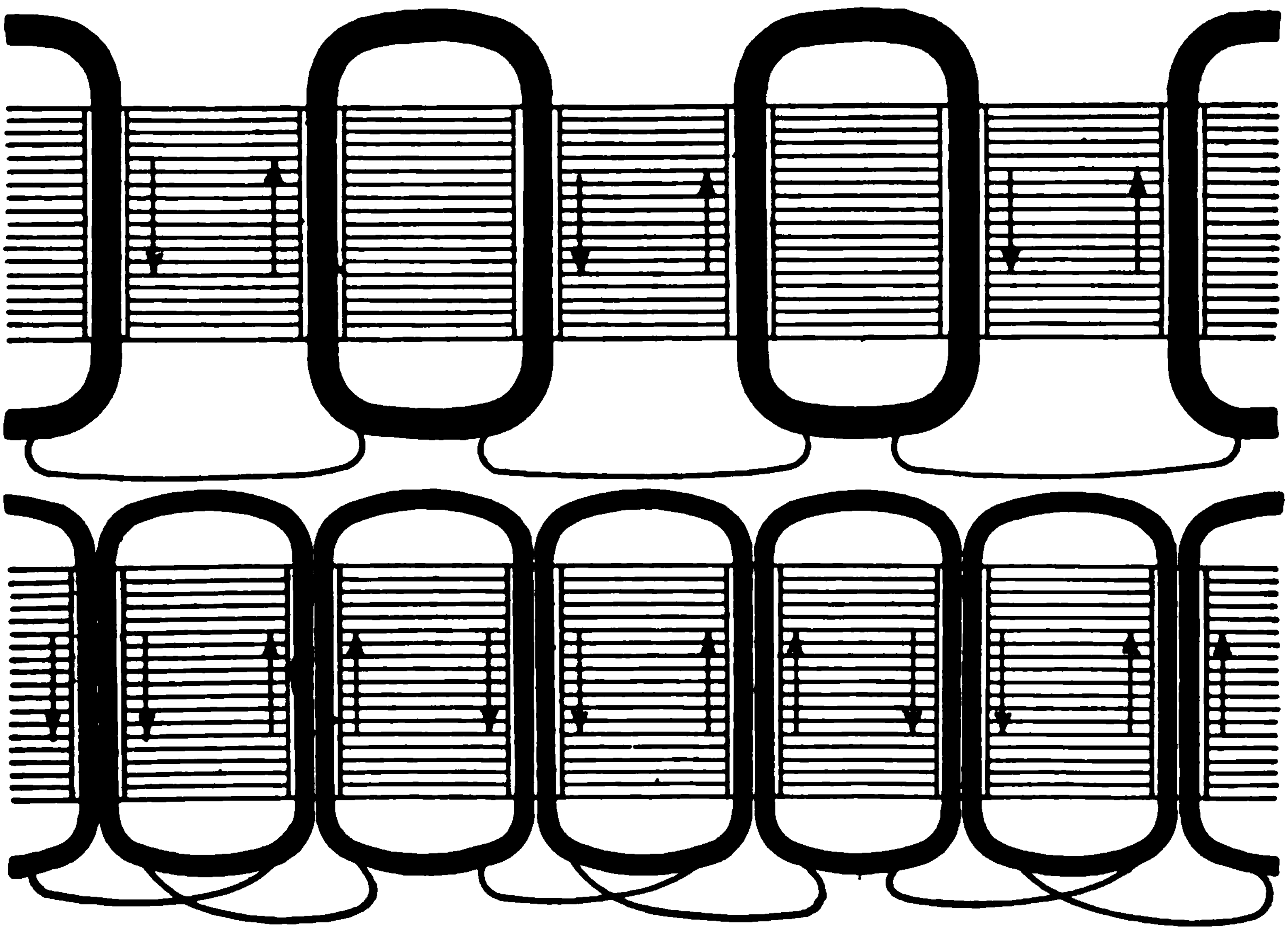


FIG. 1,530.—Two phase winding in two slots per pole per phase. This stamping distributes *the coils of each phase* into two sections, as A and B. The coils are of the "whole" type *and with six poles* the total number of slots is 4 X 6 = 24, uniformly spaced as shown.

Two Phase Armature Windings.—This type of winding can be made from any single phase winding by providing another set of slots displaced along the surface of the armature to the extent of one-half the pole pitch, placing therein a duplicate winding.

For instance: If the six pole monotooth, single phase winding, shown in fig. 1,527, be thus duplicated, the result will be the one slot two-phase



FIGS. 1,531 and 1,532.—Developed diagram of the single phase monotooth windings shown in figs. 1,527 and 1,528.

winding shown in fig. 1,529, which will have twelve slots, and will require four slip rings, or two rings for each phase.

By connecting *up the two* windings in series, the machines could be *used as a single phase, with* an increase of voltage in the ratio of 1.41 to 1

[redacted]

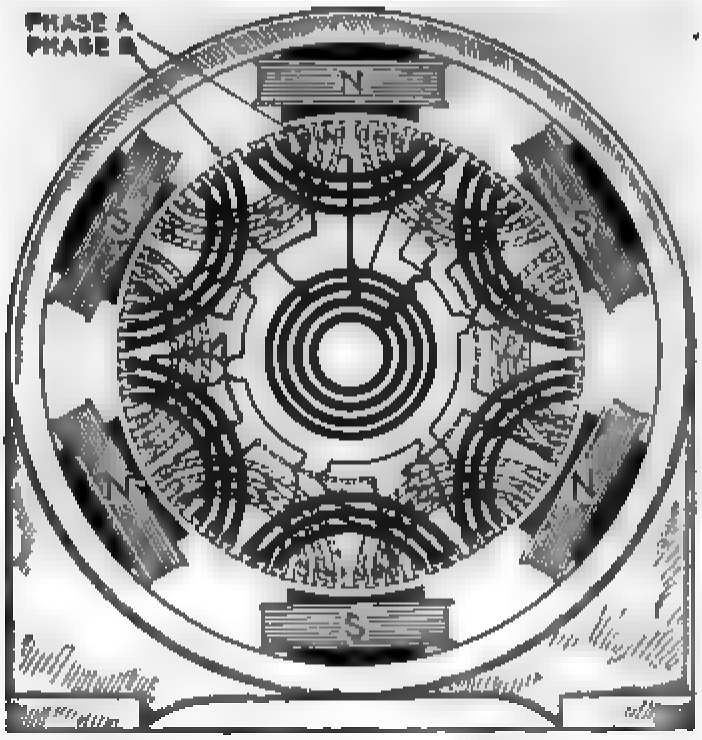


FIG. 1,533.—Two phase winding in three slots per pole per phase. The coils of each phase are of the partially distributed type, each coil being made up of three sections as shown. The direction of winding is alternately reversed.

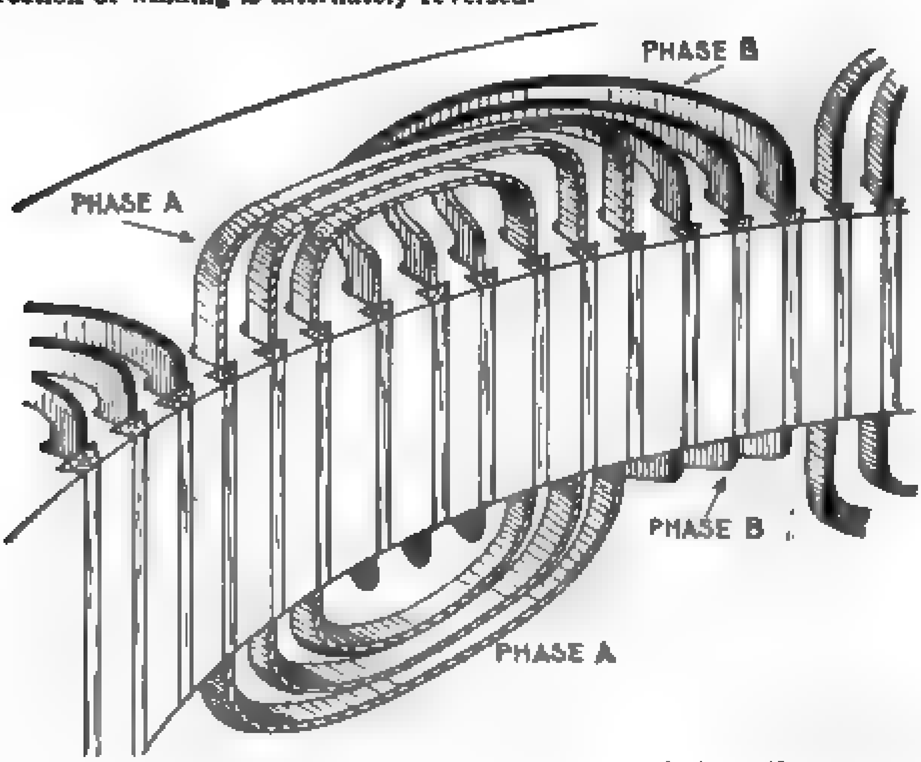


FIG. 1,534.—Section of two phase winding showing shaping of the coil ends. Every other *coil is flat, while* the alternates have their ends bent down as shown. With respect to the *shaping of the coil ends*, it is called a *two range winding*.

Ques. How must the coils be constructed for two phase windings?

Ans. They must be made of two different shapes, one bent up out of the way of the other, as in fig. 1,534.

There are numerous kinds of two phase windings; the coils may be concentrated or distributed, half coil or whole coil, etc. Fig. 1,530 shows a two phase winding with four slots per pole, and fig. 1,533 one with six slots per pole.

FIG. 1,535.—Section of Triumph armature showing method of arranging the three phase winding.

Three Phase Armature Windings.—On the same general principle applicable to two phase windings, a three phase winding can be made from any single phase winding, by placing three identical single *phase windings* spaced out successively along the

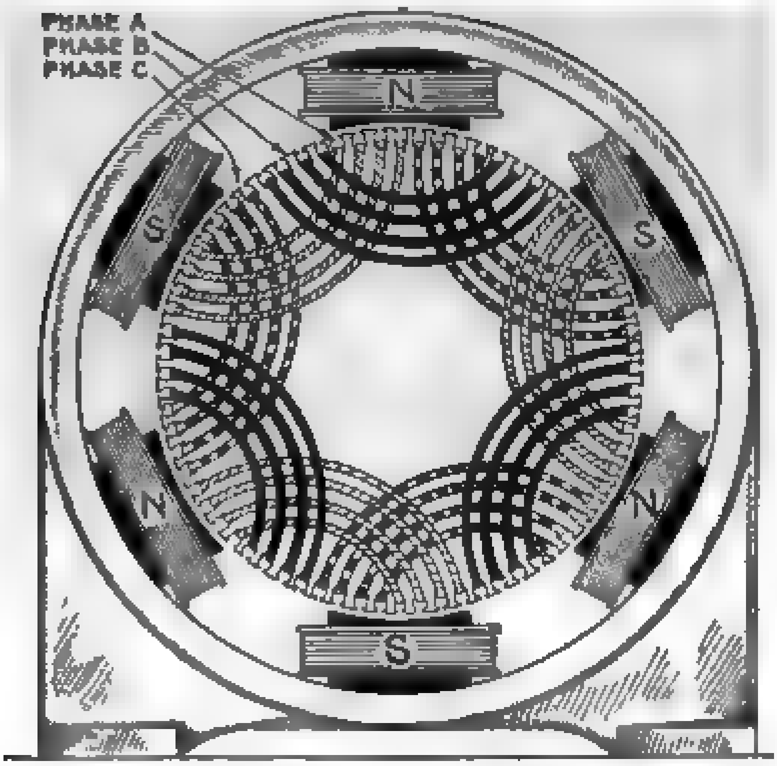


FIG. 1,536.—Three phase winding with distributed coils—wound in four slots per pole per phase; diagram showing placement of the coils.

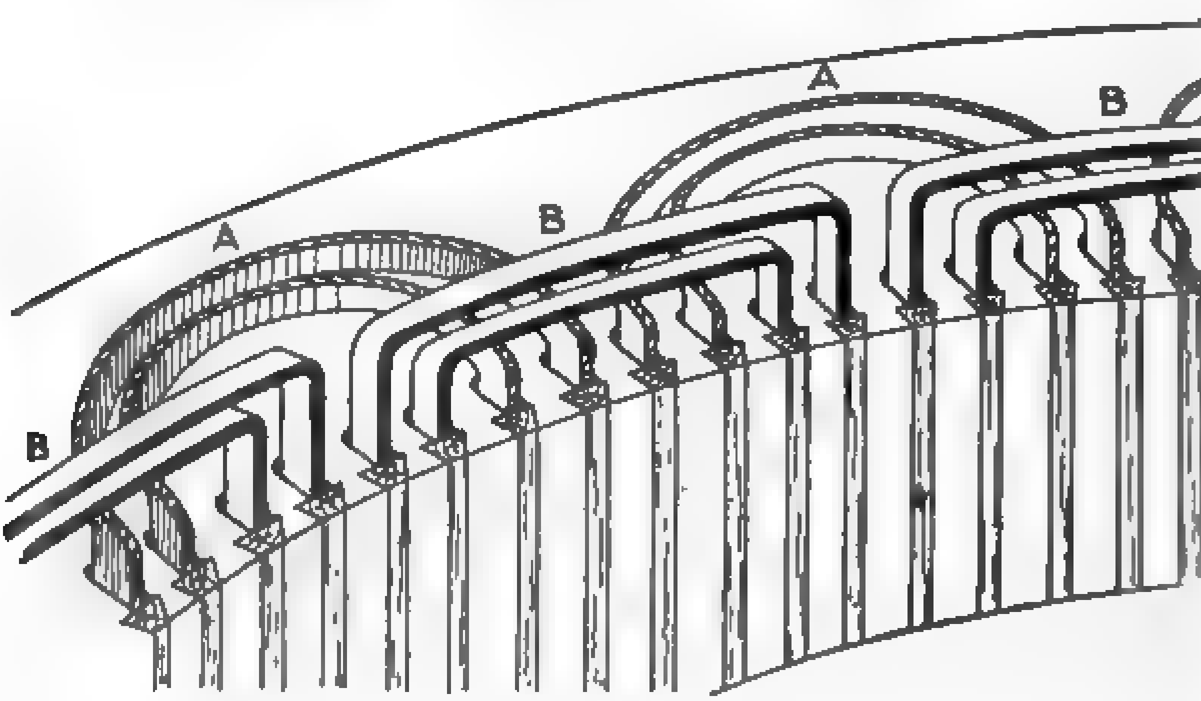


FIG. 1,537.—Treatment of coil ends in two phase, two range windings. In this arrangement *straight out* (B) and *bent up* (A) coils are used which are placed on the armature as is clearly shown in the illustration.

surface of the armature at intervals *equal to one-third and two-thirds, respectively, of the double pole pitch,* the unit in terms of which the spacing is expressed, being that pitch, which corresponds to one whole period.

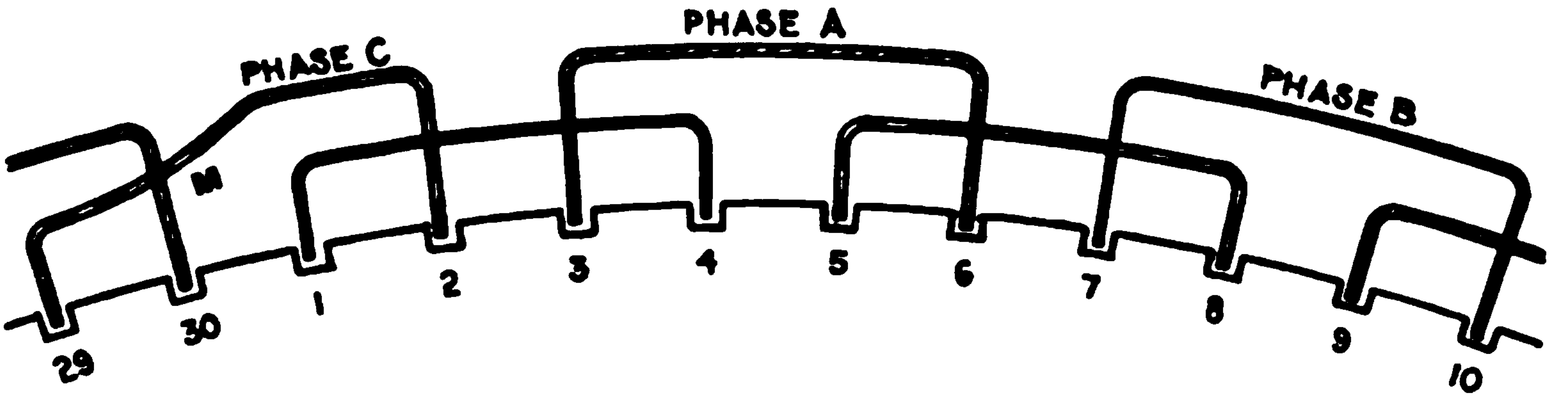


FIG. 1,538.—Three phase, 10 pole, 30 slot winding in two ranges. In this winding perfect symmetry occurs after every four poles. Accordingly in the case of an odd number of pairs of pole, one of the coils must necessarily be askew going from the inner to the outer range as at M.

Each of the three individual windings must be concentrated into narrow belts so as to leave sufficient space for the other windings between them. This limits the breadth or space occupied by the winding of any one phase to one-third of the pole pitch.

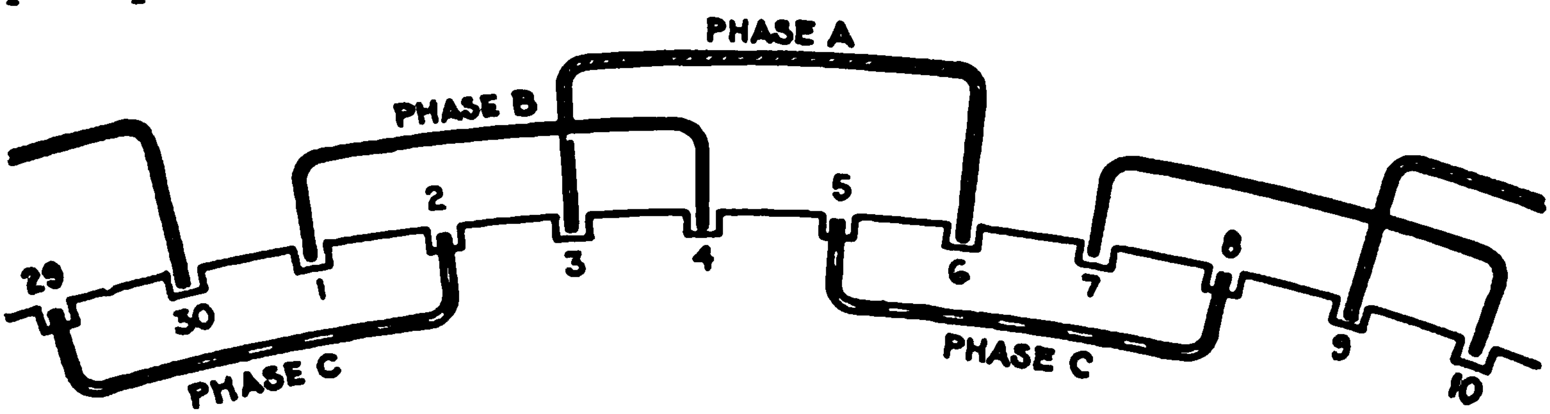


FIG. 1,539.—Three phase 10 pole 30 slot winding in three ranges. The coils of each phase are alike, those of the A phase being all in the straight out range, those in the B phase, in a bent up range, and those in the C phase in a bent down range. This arrangement has the disadvantage, that by reason of the third range, the field magnet cannot be withdrawn. This treatment of the coil ends is more clearly shown in fig. 1,540.

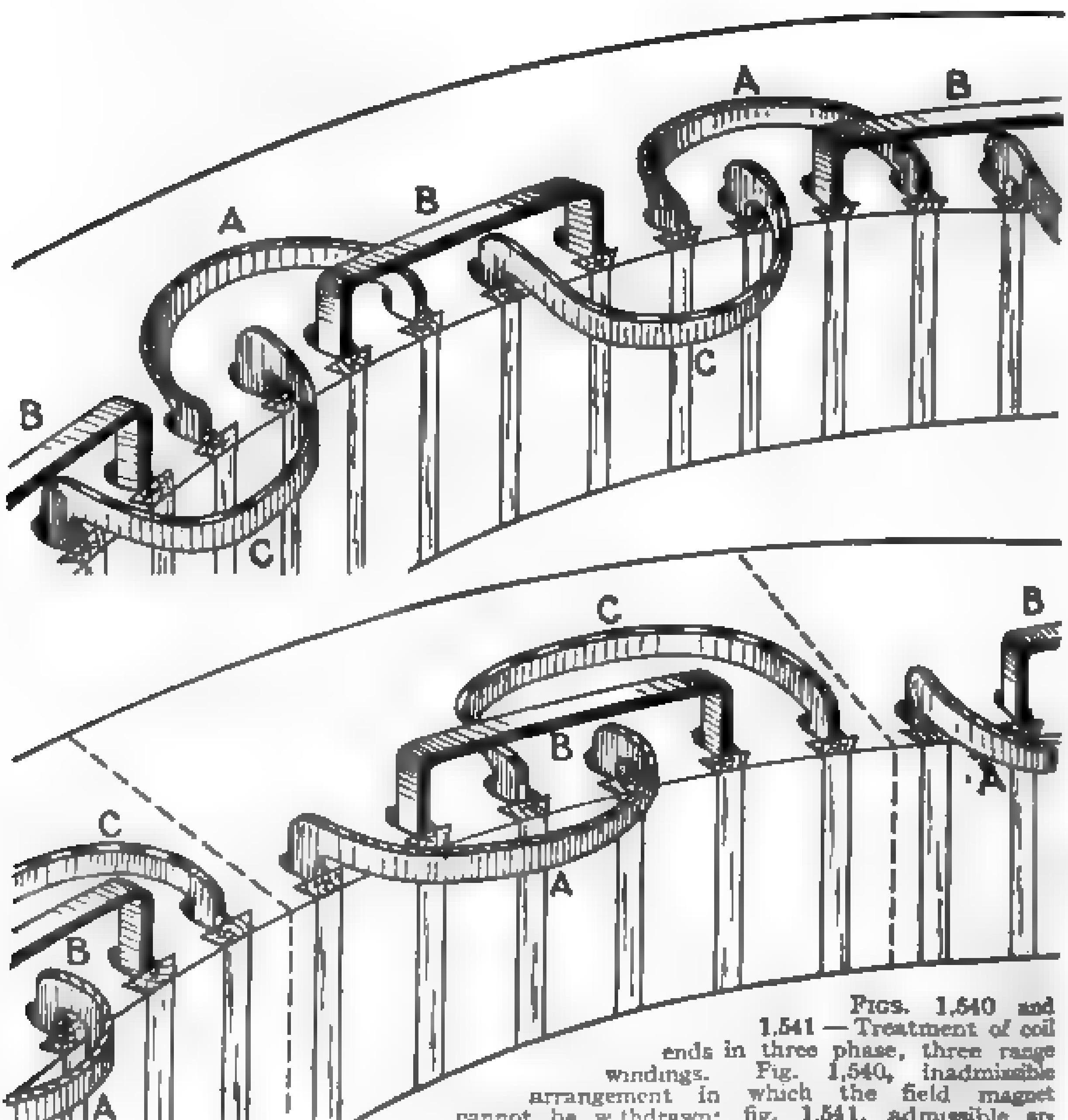
Ques. How are three phase coil ends treated?

Ans. They may be arranged in two ranges, as in fig. 1,538, or in three *ranges, as in fig.* 1,539.

[redacted]

Ques. What kind of coil must be used for three phase windings in order that the ends may be arranged in only two ranges?

Ans. Hemitropic or half coils; that is, the number of coil per phase must be equal to one-half the number of pole.



FIGS. 1,540 and 1,541 — Treatment of coil ends in three phase, three range windings. Fig. 1,540, inadmissible arrangement in which the field magnet cannot be withdrawn; fig. 1,541, admissible arrangement in which the armature segments can be *divided. This enables the* top half of armature to be removed by disconnection *without unwinding any coil.*

Grouping of Phases.—In the preceding diagrams, the general arrangement of the coils on the armature surface are shown for the numerous classes of winding. In polyphase alternators the separate windings of the various phases may be grouped in two ways:

1. Star connection;
2. Mesh connection.

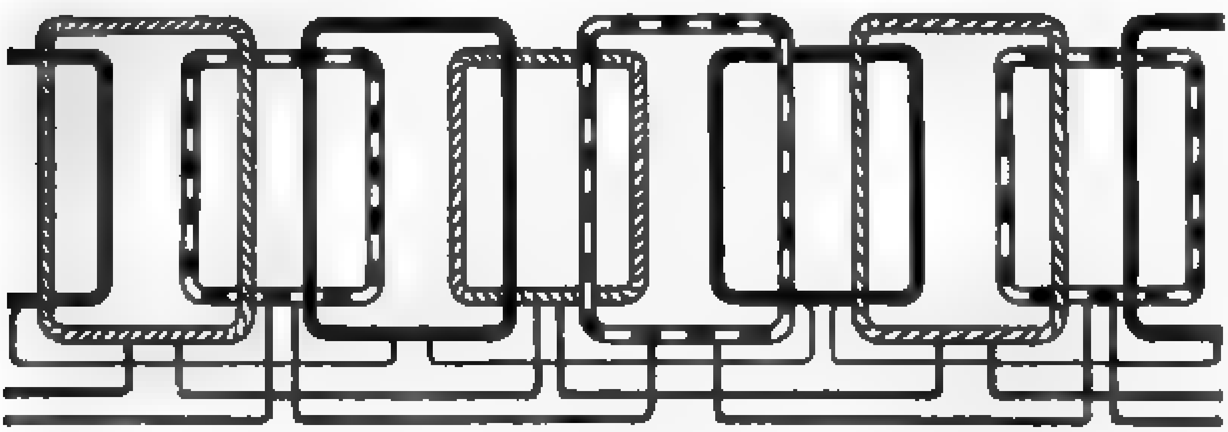


FIG. 1,542.—Three phase winding with half coils. The advantage of employing half coils is that the ends may be arranged in two ranges as shown. There is one slot per phase per pole, that is, total number of slots = 3 × number of poles.

Ques. Describe the two phase star connection.

Ans. In this method of grouping, the middle points of each of the two phases are united to a common junction M, and the

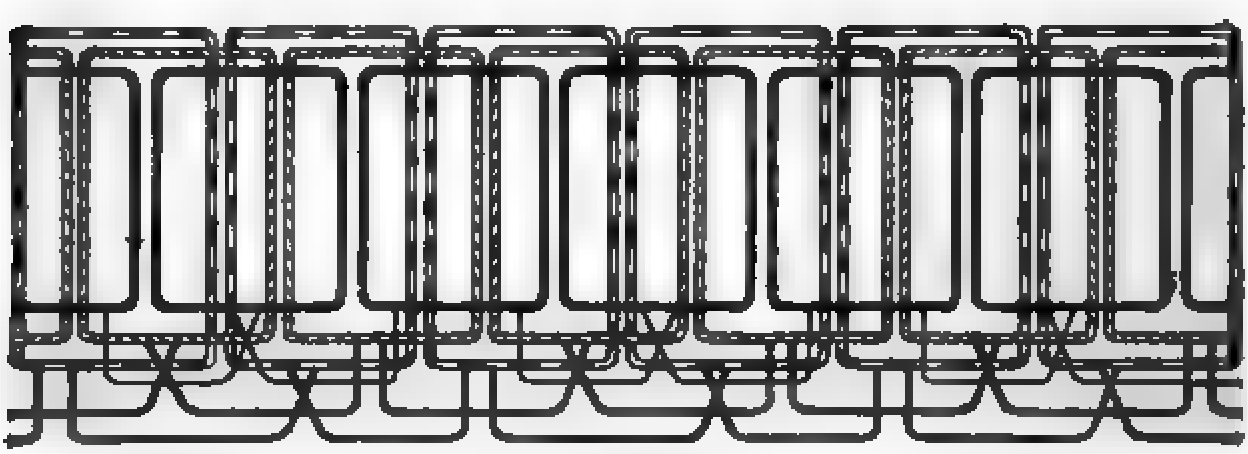


FIG. 1,543.—Three phase winding with whole coils. Two sides of adjacent coils come in one slot. Number of coils per phase = number of poles per phase. Total number of slots = 3 multiplied by *number of poles per phase*. Whole coils require the ends arranged in three *ranges as indicated*. The coils are concentrated.

four ends are brought out to four terminals *a*, *a'*, *b*, *b'*, as shown in fig. 1,544, or in the case of revolving armatures, to four slip rings.

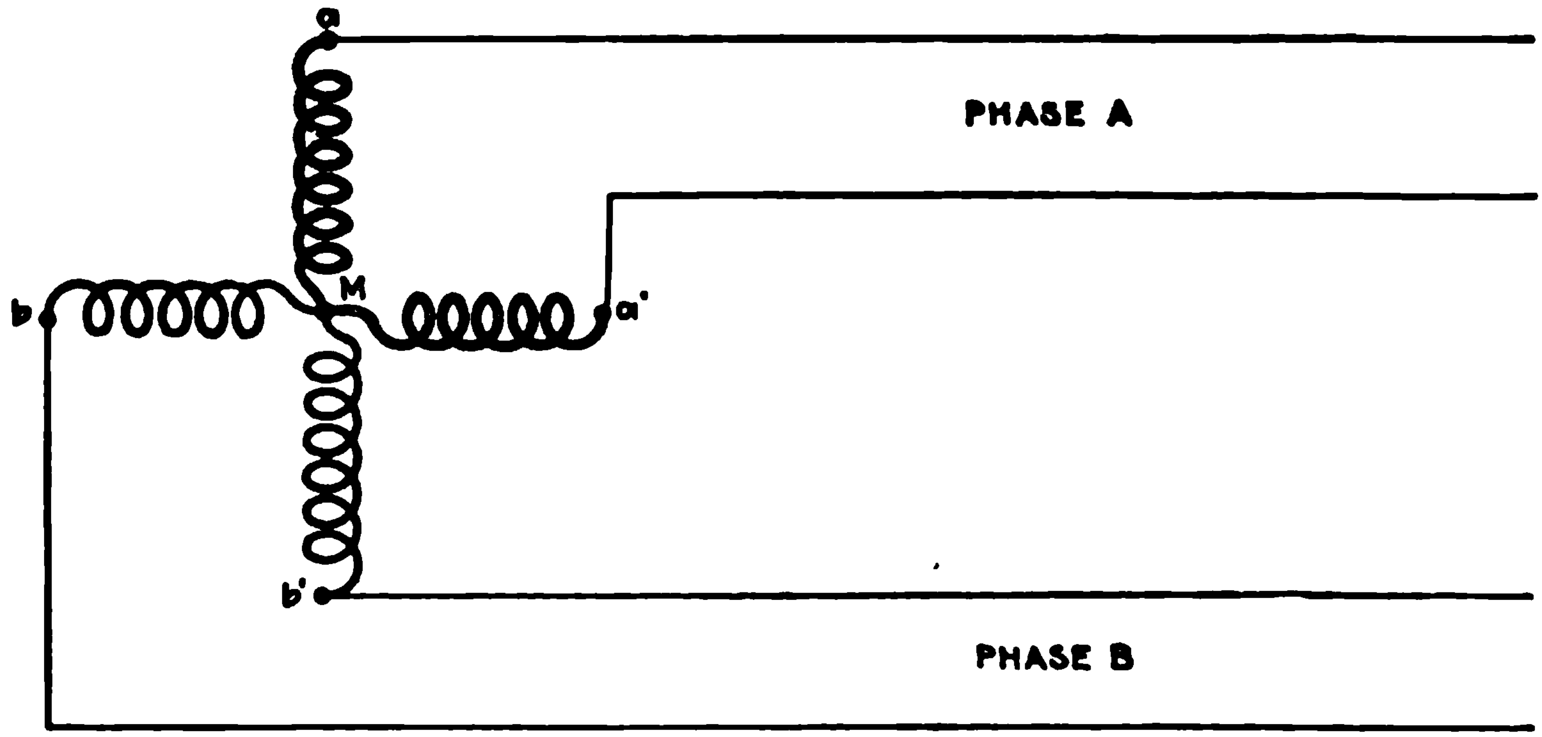


FIG. 1,544.—Diagram of two phase star grouping.

Ques. What does this arrangement give?

Ans. It is practically equivalent to a four phase system.

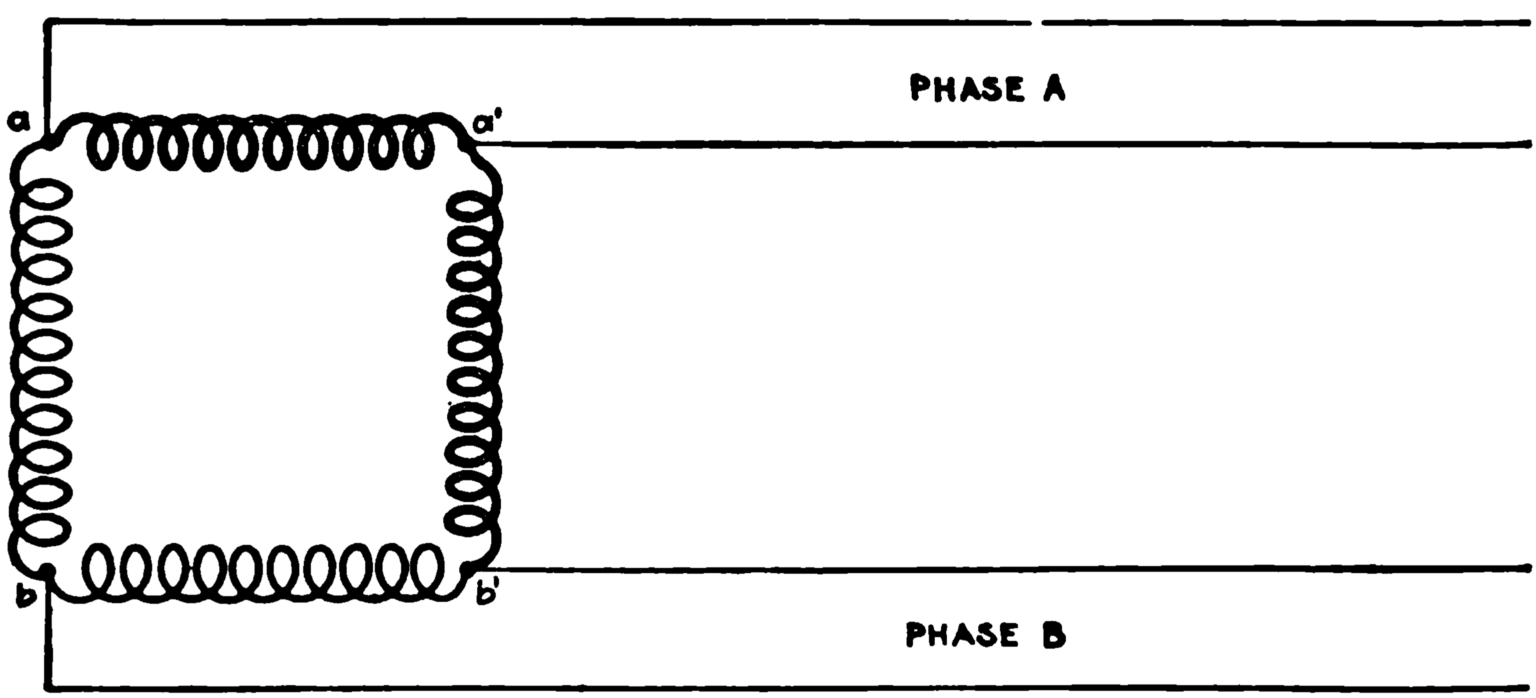


FIG. 1,545.—Diagram of two phase mesh grouping.

Ques. How is the two phase mesh connection arranged?

Ans. In this style of grouping, the two phases are divided

into two parts, and the four parts are connected up in cyclic order, the end of one to the beginning of the next, so as to form a square, the four corners of which are connected to the four terminals *a*, *b*, *a*′, *b*′, as shown in fig. 1,545, or in the case of revolving armatures, to four slip rings.

Ques. Describe a three phase star connection?

Ans. In three phase star grouping, one end of each of the three circuits is brought to a common junction M, usually

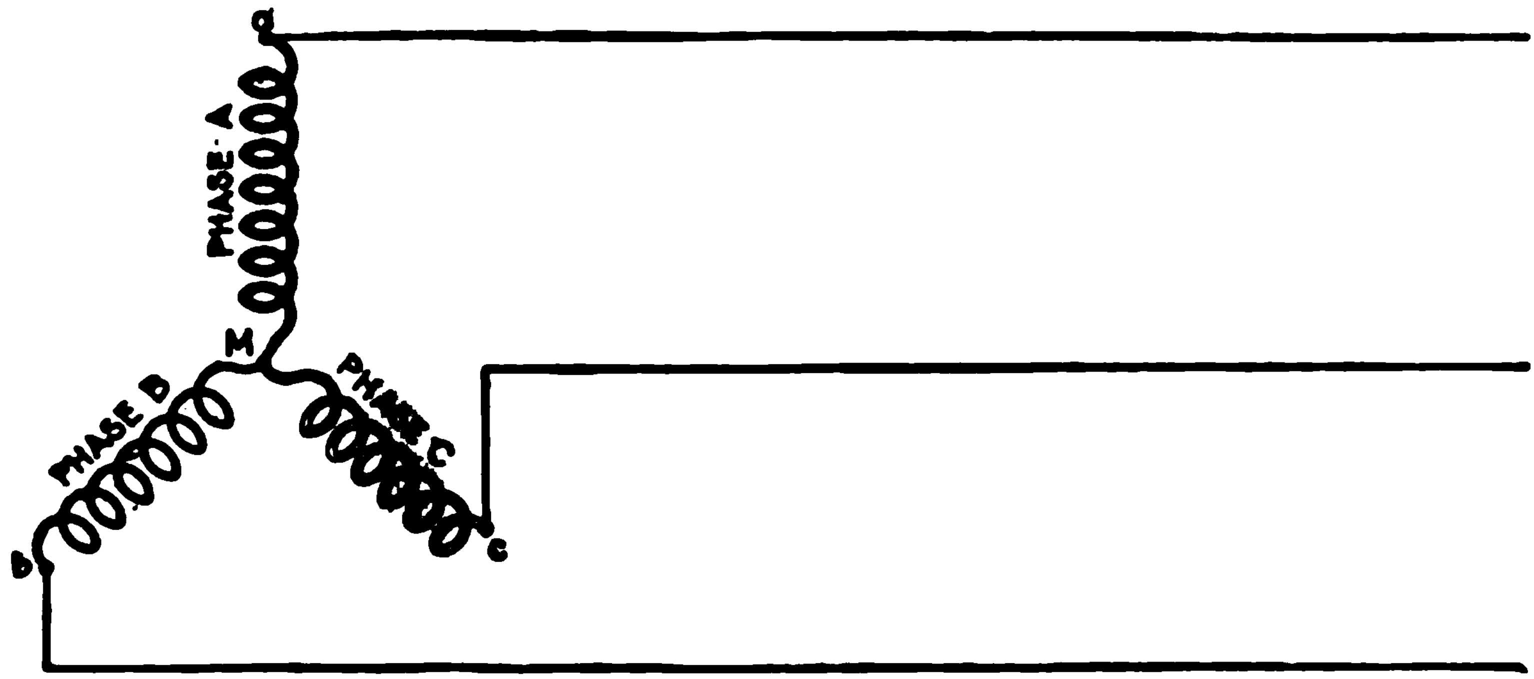


FIG. 1,546.—Diagram of three phase star grouping, commonly called Y grouping owing to its resemblance of the letter Y. The current in each main is obviously equal to the current in each phase winding, but the terminal pressure is the vector sum of the pressures in the component phase windings, that is, $\sqrt{3}$ multiplied by the pressure in one phase.

insulated, and the three other ends are connected to three terminals *a*, *b*, *c*, as shown in fig. 1,546, or in the case of revolving armatures to three slip rings.

Ques. What other name is given to this connection, and why?

Ans. It is commonly called a **Y** connection or grouping owing to the resemblance of its diagrammatic representation to the letter **Y**.

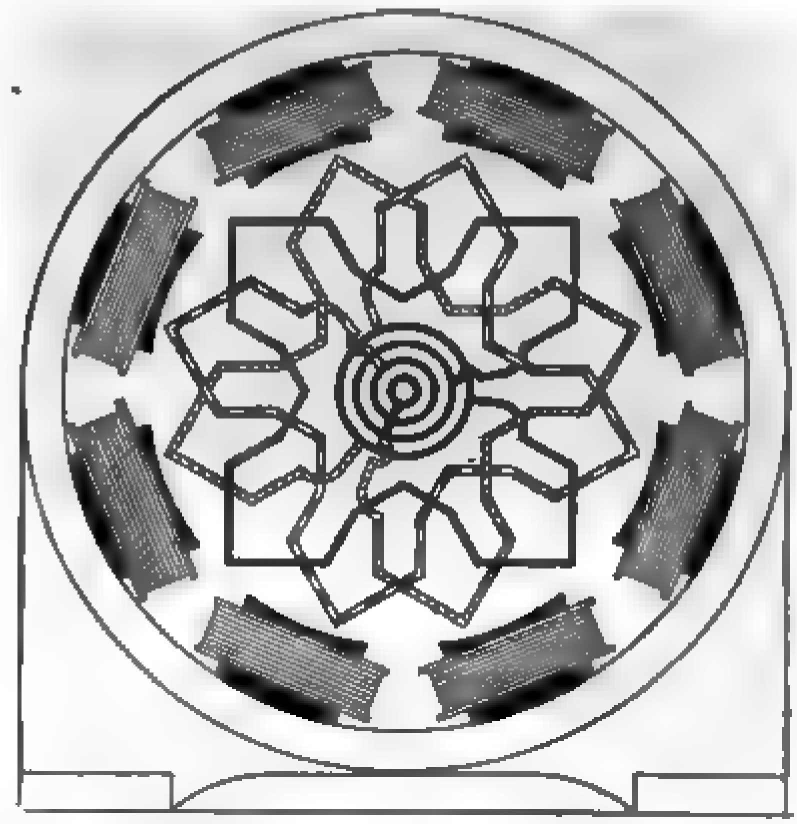


FIG. 1,547.—Radial diagram of three phase, one slot winding with Y connection.

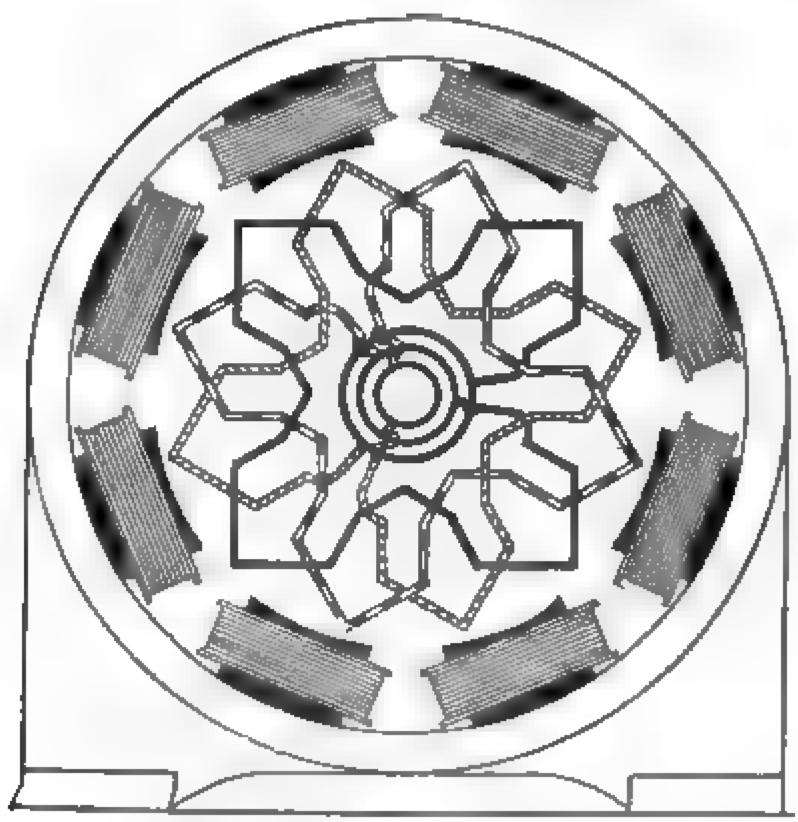


FIG. 1,548.—Radial diagram of three phase one slot winding with delta connection.

Ques. How is a three phase mesh connection arranged?

Ans. The three circuits are connected up together in the form of a triangle, the three corners are connected to the three terminals, *a*, *b*, *c*, as shown in fig. 1,549, or in the case of revolving armatures to three slip rings.

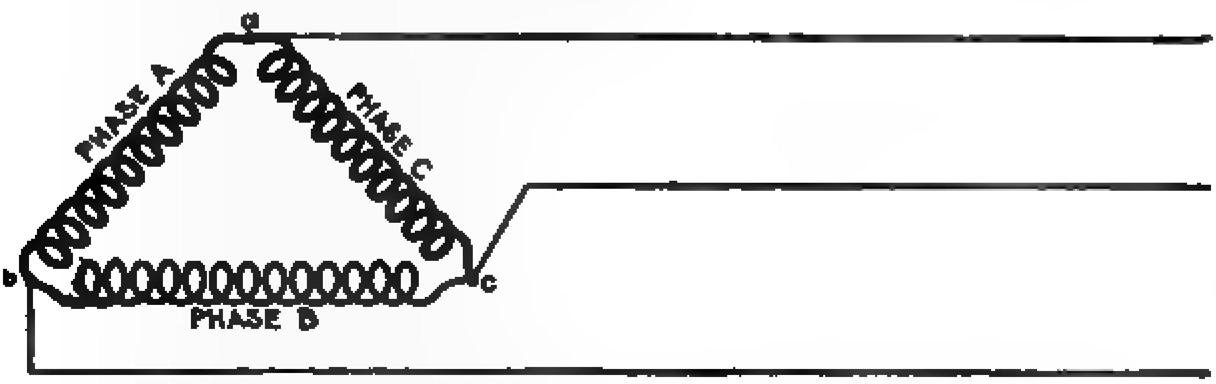


FIG. 1,549.—Diagram of three phase mesh grouping, commonly called delta grouping owing to its resemblance to the Greek letter Δ. The voltage at the terminals is equal to the voltage in one phase, and the current in each line is equal to the vector sum of the currents in two phases, that is, it is equal to $\sqrt{3}$ multiplied by the current in one phase.

Ques. What other name is given to this style of connection, and why?

Ans. It is commonly called a *delta* grouping on account of the resemblance of its diagrammatic representation to the Greek letter Δ.

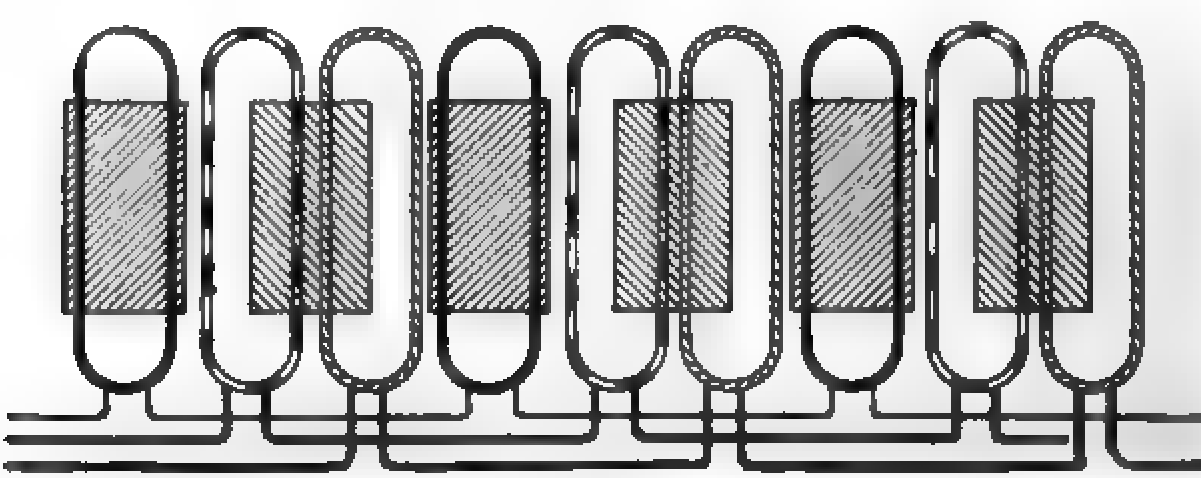


FIG. 1,550.—Three phase *winding with* short coils. The use of short coils as here shown, in *which the coil breadth = ⅔ pole pitch*, avoids the necessity of overlapping.

In polyphase working, it is evident that by the use of four equal independent windings on the armature, connected to eight terminals or slip rings, a two phase alternator can be built to supply currents of equal voltage to four independent circuits. Likewise, by the use of three equal independent windings, connected to six terminals or slip rings, a three phase alternator can be made to supply three independent circuits.

This is not the usual method employed in either case, however, as the star grouping or mesh grouping methods of connection not only

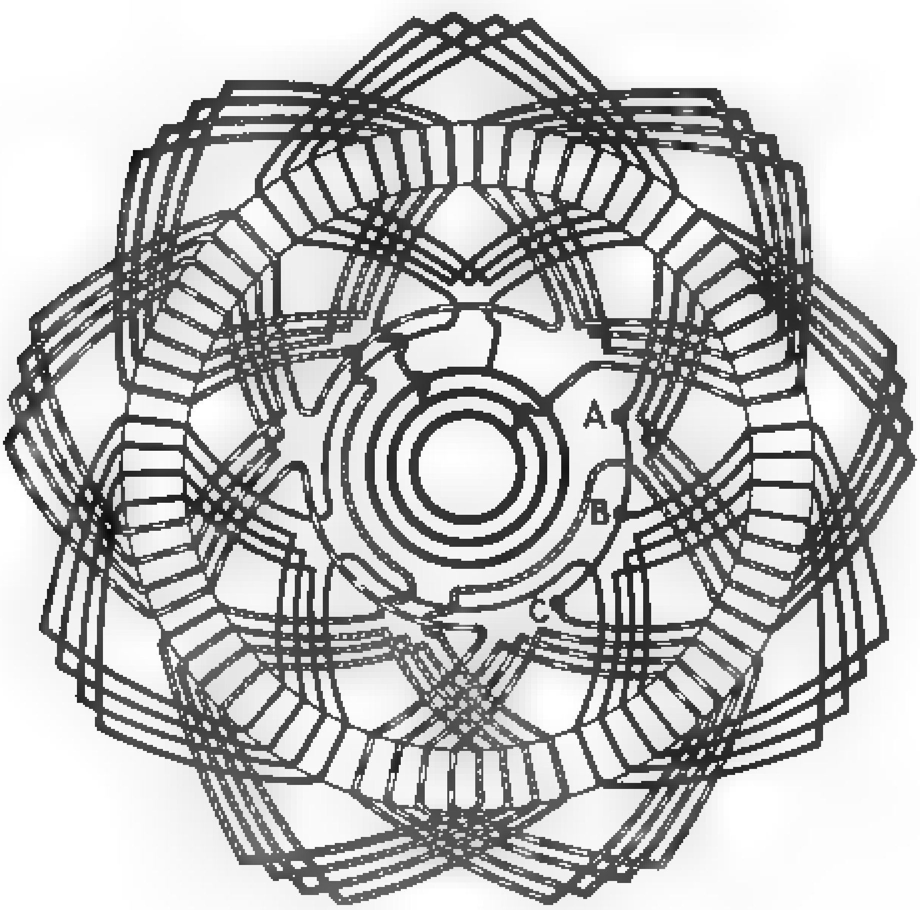


FIG 1,551.—Radial diagram of three phase *lap* winding with star connection.

gives the same results, but also, in star grouping, a greater plurality of voltages for the same machine, and a higher voltage between its main terminals.

Radial diagrams of the arrangement and connections of Y *grouping of lap windings* and wave windings for three phase alternators are *shown by figs.* 1,551 and 1,552.

Ques. In three phase star grouping, what is the point where the phases join, called?

Ans. The star point.

Ques. In a three phase star connected alternator what is the voltage between any two collector rings?

Ans. *It is equal to the voltage generated per phase multiplied by* $\sqrt{3}$ *or* 1.732.

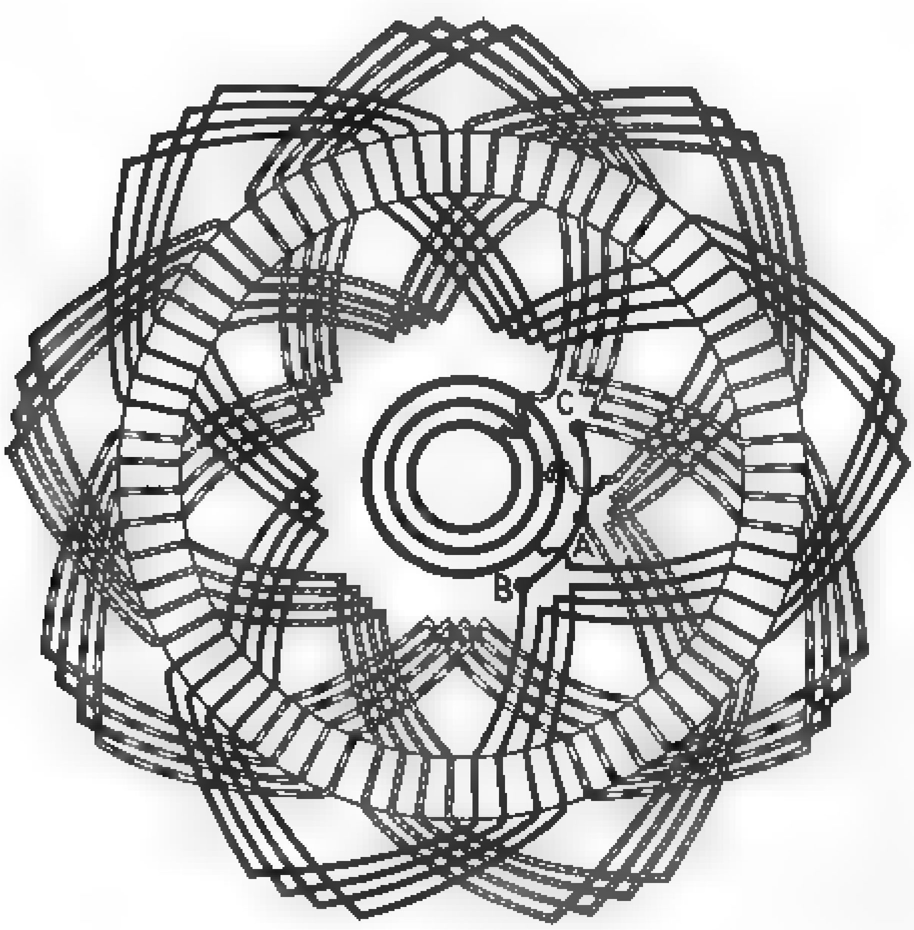
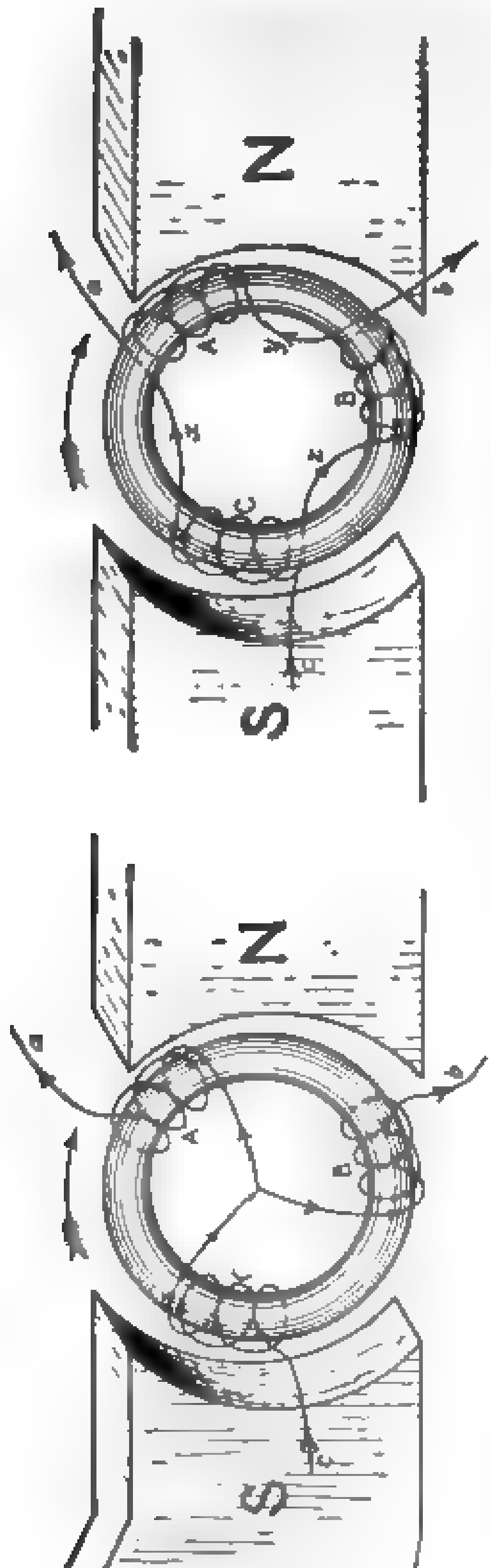


FIG. 1,552.—Radial diagram of three phase wave winding with star connection.

Ques. In a three phase star connected alternator what is the value of the current in each line?

Ans. The same as the current in each phase winding.



Figs. 1,553 and 1,554.—Gramme ring armatures showing three phase star and mesh connections, respectively, with direction of currents in the coils. In the figures, the coils A, B, C, are spaced at equidistant positions on the ring core. The arrow heads represent the directions of the induced pressures or currents for the position shown, the rotation being clockwise. In coil A the pressure is increasing, in coil B it is diminishing, but is in the same direction as in A, whereas in coil C it is also diminishing, but is in the opposite direction to what it is in coils A and B. As the rings rotate the three coils have similar alternations of pressure induced in them, but differ in phase. If *a*, *b* and *c* be joined to collector rings three phase currents can be supplied to the outer circuits. In fig 1,553 at the instant represented *a* and *b* are giving their current to their lines, while *c* is receiving from its line a current equal to the sum of *a* and *b*. In fig 1,554, at the instant represented, the currents sent out from *a* will be equal to the sum of the currents in *x* and *y*, and intermediate between them in phase. The current from *b* will be equal to the difference of the currents in *z* and *y*, and of intermediate phase, while similarly the current received by *c* will be equal to the sum of the currents in *x* and *z*.

Ques. What is the value of the total output in watts of a star connected alternator?

Ans. It is equal to the sum of the outputs of each of the three phases. When working on a non-inductive load, the total output of a star connected alternator is equal to $\sqrt{3}$ multiplied by the product of the line current and line voltage.

Ques. What is the value of the line voltage in a three phase delta connected alternator?

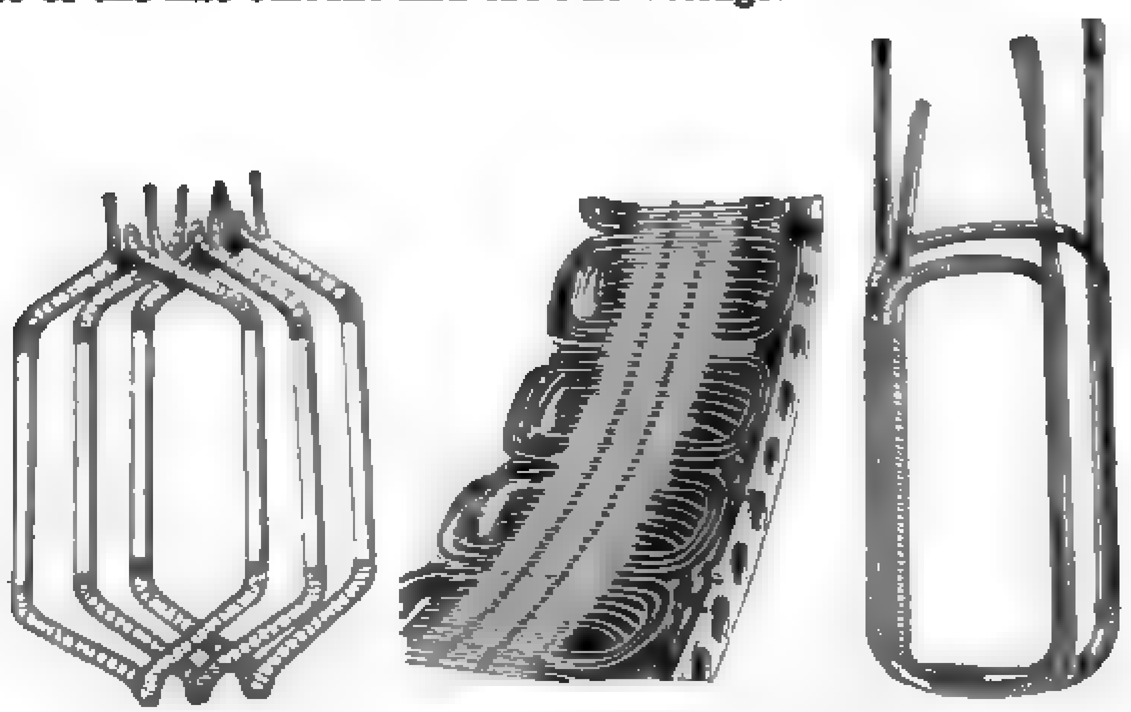
Ans. It is equal to the voltage generated in each phase.

Ques. What is the value of the line current in a three phase delta connected alternator?

Ans. It is equal to the current in each phase multiplied by $\sqrt{3}$.

Ques. What is the total output of a three phase delta connected alternator working on a non-inductive load?

Ans. The total watts is equal to $\sqrt{3}$ multiplied by the product of the line current and the line voltage.



FIGS. 1,555 to 1,557.—Separate coils, and section of Allis-Chalmers alternator with coils in place. Numerous openings are provided in the frame through which air currents, set up by the revolving field, can pass freely and carry off heat. Shields are provided to protect the armature coils where they project beyond the core. In assembling the core spacing segments are placed at intervals to form ventilating ducts. After the coils have been covered with insulating materials and treated with insulating compound, the parts that are to lie in the slots are pressed to exact size in steam heated moulds. This runs the insulating material into all the small spaces in the coil so as to exclude moisture, it also makes the coil structure firm and solid. The projecting ends of the coils are heavily taped, suitable supports being provided for the coil connections so that they cannot become displaced on account of stresses due to short circuits or other causes. On high pressure machines the armature terminals are arranged so that it is impossible for an attendant to make accidental contact with them.

Ques. What are the features of the star connection?

Ans. It gives a higher line voltage than the delta connection for the same pressure generated per phase, hence it is suited for machines of high *voltage* and moderate current.

The delta connection gives a lower line voltage than the star connection for the pressure generated per phase, and cuts down the current in the inductors; since the inductors, on this account, may be reduced in size, the delta connection is adapted to machines of large current output.

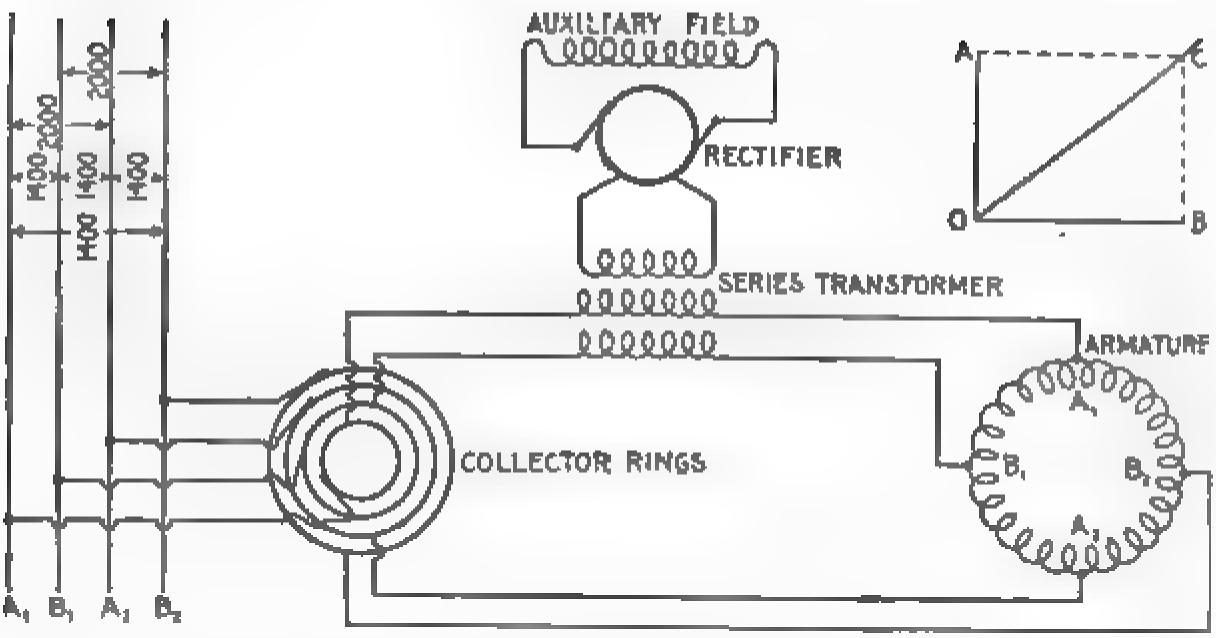


FIG. 1,558.—Diagram of Westinghouse two phase composite wound alternator, showing connections between two phase armature and a single phase rectified and composite field winding. The arrangement makes use of a series transformer, mounted on the spokes of the armature. By means of this series transformer the voltage delivered to the rectifying commutator and the fields is much less than that generated by the machine. The armature of this machine is of the closed coil single winding type, all the armature inductors being connected with each other to form a closed circuit which resembles to a certain extent the ordinary drum winding of a multi-polar direct current machine. This winding is tapped out at two points per pole just as is the continuous winding of a two phase rotary converter, these taps running to collector rings through which the currents are delivered to the outside circuits. On account of this connection of both phases to one winding there is a definite voltage set up between the inductors of phase A, and of phase B, this voltage being shown by the figures given in the diagram. The arrangement is adapted for two phase work by fitting the series transformer for the auxiliary field excitation with two primaries connected respectively in one leg of each of the two phases; thus the transformer is excited by two currents normally ¼ period out of phase with each other The result upon the secondary is a combination of the effects of the two primary currents, the voltage delivered by the secondary being intermediate in phase between those pressures which would be separately set up by the two primaries. This combination effect is shown in the small diagram in the upper right hand corner of the illustration If O A be the effect set up in the secondary of the series transformer by the primary current of phase A, and O B be the effect set up by the primary current of phase B, O C represents in magnitude and phase relation the resultant effect upon the secondary. It is readily seen that this resultant is not equal to the arithmetical sum of the two components since, to a certain extent, they work at cross purposes. However, if either one of them increase the resultant effect increases, although not in exact proportion. If the load remain balanced, the two components remaining equal to each other, the resultant O C varies in exact proportion to any changes in the components. If the load become unbalanced, the resultant swings around more nearly into phase with the larger load; thus if O B become greater, O A remaining the same, O C swings around, becoming more nearly horizontal. This requires a readjustment of the position of the brushes on the commutator to set them properly for minimum sparking, an adjustment exactly similar to that required when the power factor of the load changes.

Ques. How is the path and value of currents in a delta connected armature determined?

Ans. Starting with the inductors of one phase opposite the middle of the poles, assume the maximum current to be induced

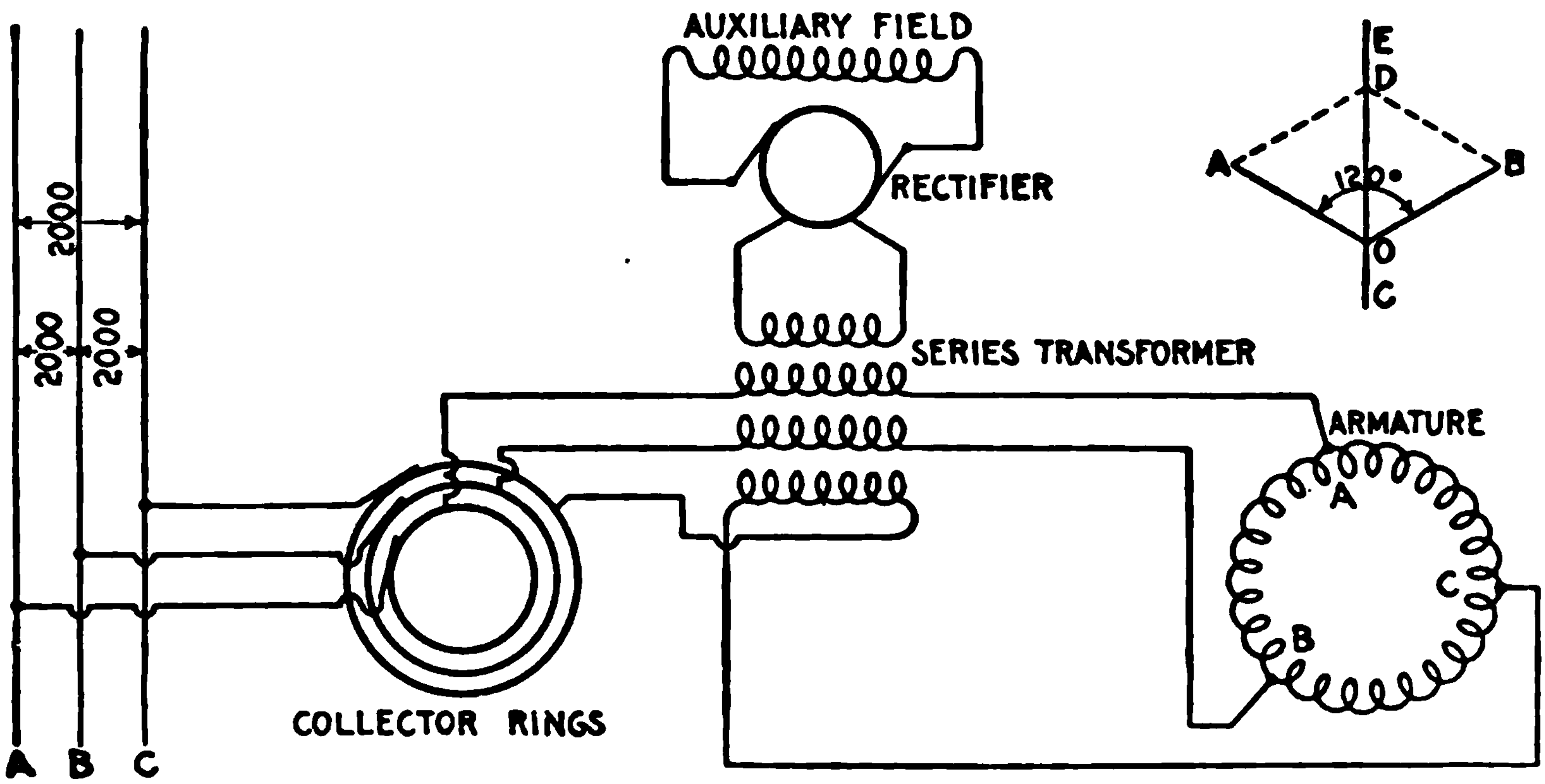


FIG. 1,559.—Diagram of Westinghouse three phase composite wound alternator. The armature inductors are of the closed coil or delta connected type, but are tapped at three points per pair or poles to the three collector rings. All three connections between the armature coils and the collector rings run through primary circuits of the series transformer within the armature, these three primaries each giving their own effect upon the secondary. Since the resultant of three equal alternating electromotive forces 120° apart is zero, so that some special arrangement must be adopted to make these electromotive forces act with instead of against each other. The arrangement is a reversal of the connections of one of the primaries of the series transformer. This is shown in the case of the lowest primary indicated in the diagram. The combination of the effects of the three primaries is again indicated in the small vector diagram in the upper right hand corner. Here O A is the effect of one primary, O B that of another ⅓ of a period displaced from the former in phase, and O C that which the third would exert were it not reversed, but the reversal brings the effect of this third coil into the phase relation O D, so that the three are only 60° apart. The combination of O A and O B is equal to O C, which combined again with O D gives a resultant effect, O E. In this case, as in the other, the effect upon the series field does not remain exactly proportional to the load unless the latter is balanced; in fact, an increased current through the one leg represented by O D, affects the series field as much as an equal increase in each of the other legs put together. Practically, however, any increase of the load—distributed as it must be in two legs at least—increases the field excitation so that proper regulation is secured.

NOTE.—In the star connected armature the proper ends to connect to the common terminal or star point are determined as follows: Assume that the inductor opposite the middle of a pole is carrying the maximum current, and mark its direction by an arrow. Then the current in the inductors on either side of and adjacent to it will be in the same direction. As the maximum current must be *coming from* the common terminal, the end toward which the arrow points must be connected to one of the rings, while the other end is connected to the common terminal. The current *in the* two adjacent inductors evidently must be into the common *terminal, hence the* ends toward which the arrows point must be co*nnected* *to the common terminal, while their* other ends are connected to the remaining

at this moment; then but one-half of the same value of current will be induced at the same moment in the other two phases, and its path and value will best be shown by aid of fig. 1,560, in which X may be taken as the middle collector ring, and the maximum current to be flowing from X toward Z. It will be seen that no current is coming in through the line Y, but part of the current at Z will have been induced in the branches *b* and *c*.

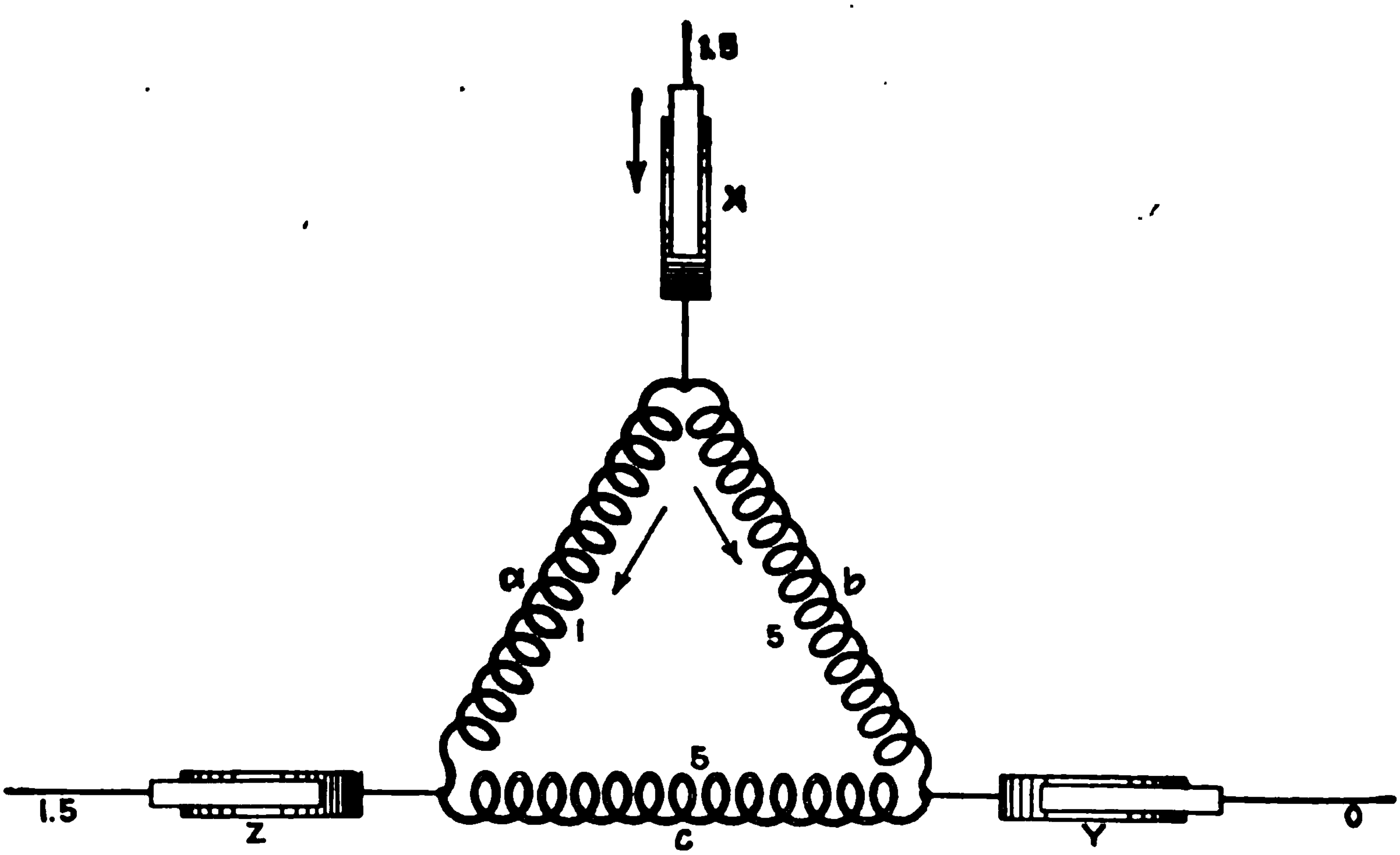


FIG. 1,560.—Diagram showing determination of path and value of current flowing in delta connected armature.

Ques. Since most three phase windings can be connected either Y or delta, what should be noted as to the effects produced?

Ans. With the same winding, the delta connection will *stand 1.732* as much current as the Y connection, but will give *only 1 ÷ 1.732* or .577 as much voltage.

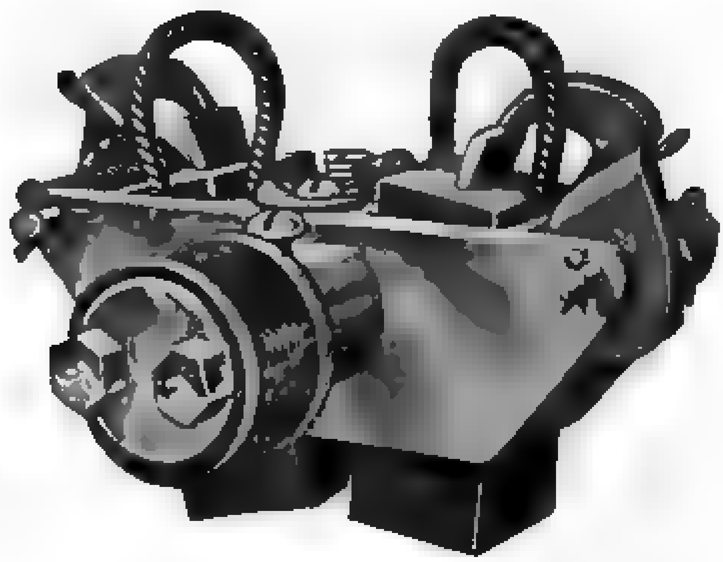


FIG. 1,561.—Triumph brushes and brush holder. The holder is of the box type provided with an adjustable tension spring, making the brushes self-feeding. Each holder is carried on insulated studs attached to a cast iron yoke which is mounted on the bearing.

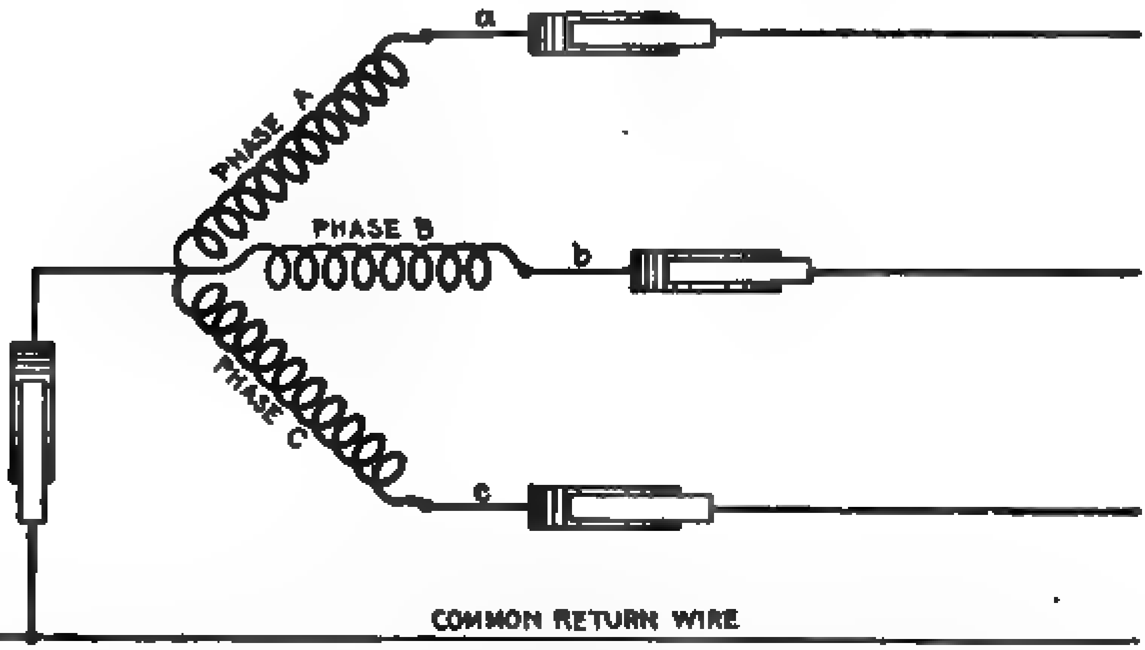


FIG. 1,562.—Diagram of Y connection with a common return wire. When the three lines leading from *a*, *b* and *c* are equal in resistance and reactance, or in other words when the system is *balanced*, the currents of the three phases are equal and are 120° apart in phase (each current lagging behind its pressure by the same amount as the others) and their sum is at each instant equal to zero. In this case the resultant current being equal to zero there is no need of a common return wire. However, in some cases, where power is distributed from transformers or three wire systems, the different branches are liable to become unbalanced. Under such circumstances the common return wire is sometimes used, being made large enough to take care of the maximum unbalancing that may occur in operation. The return wire is used sometimes on alternators that furnish current mostly *for lighting work.*

Chain or Basket Winding.—One disadvantage in ordinary two-range windings is that two or three separate shapes of coil are required. The cost of making, winding, and supplying spares would be less if one shape of coil could be made to do for

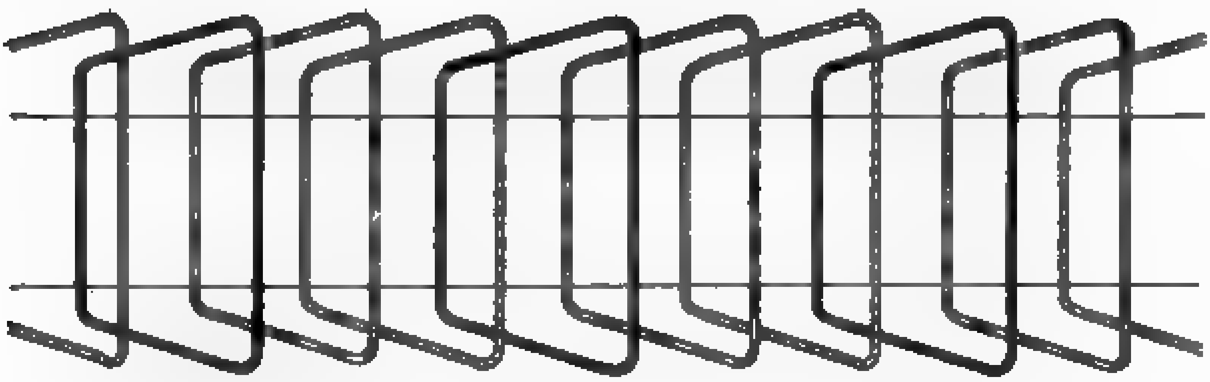


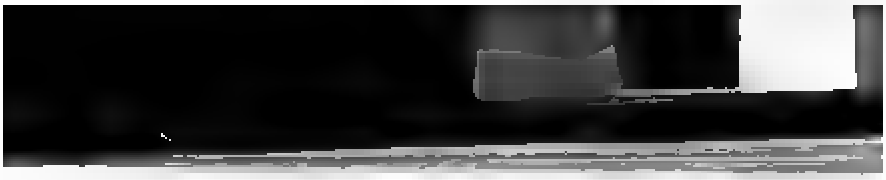
FIG. 1,563.—Diagram showing chain winding. In this method of winding the coils are all similar with long and short sides. It obviates the extra cost of making coils of several different shapes. The diagram represents a winding for one slot per pole per phase.

all phases. One way of accomplishing this is by the method of chain winding, in which the two sides of each coil are made of different lengths, as shown in fig. 1,563, and bent so that they can lie behind one another.

FIG. 1,564.—General Electric terminal board showing cables leading to three phase winding.

In the case of open slots the coils may be former wound and afterwards wedged into their places.

In chain winding the adjacent coils link one another as in a *chain (hence,* the name); the winding is similar to a skew coil

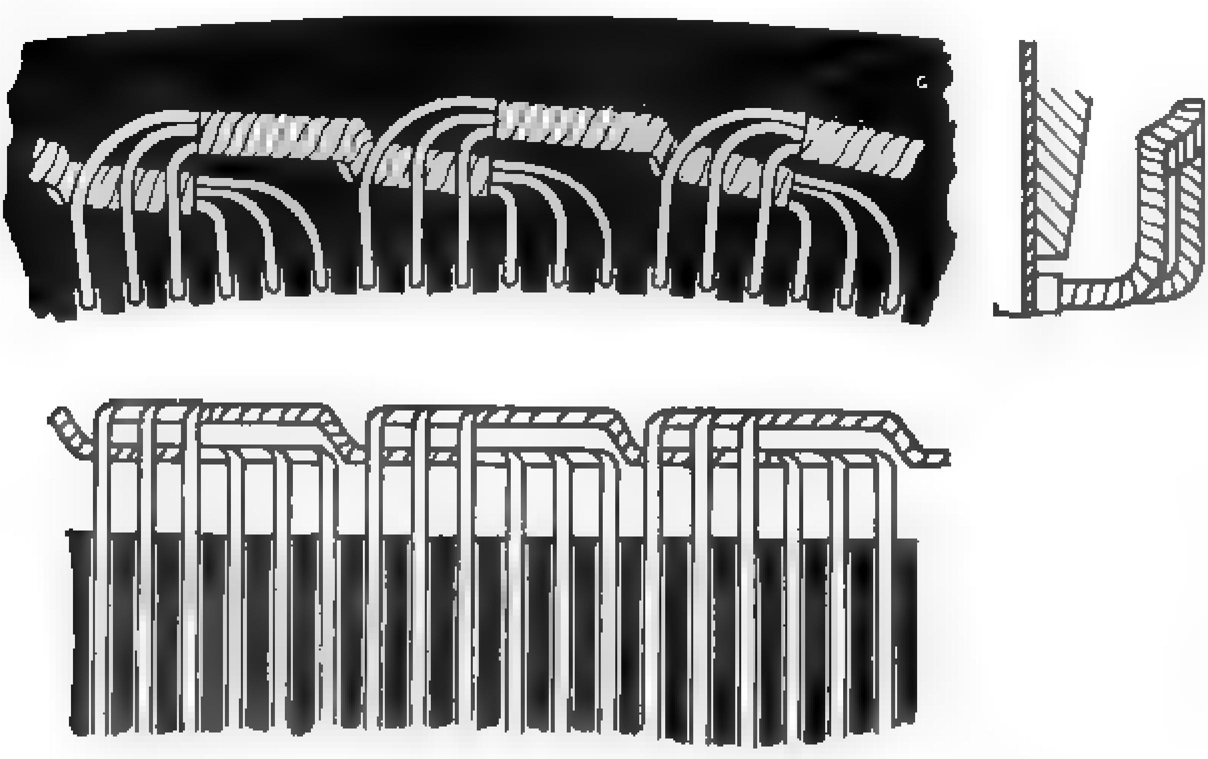


winding. This plan of winding is supposed to have some advantage in keeping coils of different phases further separated than the two range plan.

FIG. 1,566.—Section of armature winding of Allis-Chalmers 500 kw. three phase water wheel alternator. The coils are of the concentrated "half" type. Each coil is completely insulated before being placed on the core and no insulation is placed in the slot itself. The ends of the coils where they project beyond the slots are heavily taped. Where necessary suitable supports are provided for the coil connections so that they cannot become displaced on account of stresses due to short circuits or other causes. The winding is of the "chain" type. This is shown by the way the coils are connected together at the right. The armature terminals are either provided with insulated connectors or are led to a marble terminal board on which the terminals are so mounted and protected that it is impossible for an attendant to make accidental contact with them. The position of the illustration would indicate a horizontal alternator but the machine is of the vertical type; the lug on the right shows this, being used for adjusting the alternator on the foundation.

Skew Coil Winding.—In this type of winding the object is to shape the coils so that all may be of one pattern. This is accomplished by making the ends skew shape as shown in figs. 1,566 to 1,568.

Fed-in Winding.—This name is given to a type of winding possible with open or only partially closed slots, in which coils previously formed are introduced, only a few inductors at a time



FIGS. 1,566 to 1,568 Views of a section of skew coil winding, so called on account of the skew shape given to the coil ends in order that all the coils may be of one shape.

if necessary. They are inserted into the slots from the top, the slot being provided with a lining of horn fibre or other suitable material, which is finally closed over and secured in place by means of a wedge, or by some other suitable means. An example of a fed-in winding is shown in figs. 1,566 and 1,568.

Imbricated Winding.—This is a species of spiral coil winding in which the end connections are built up one above the other, either in a radial, or in a horizontal direction.

The winding is used especially on the armatures of turbine alternators and dynamos.

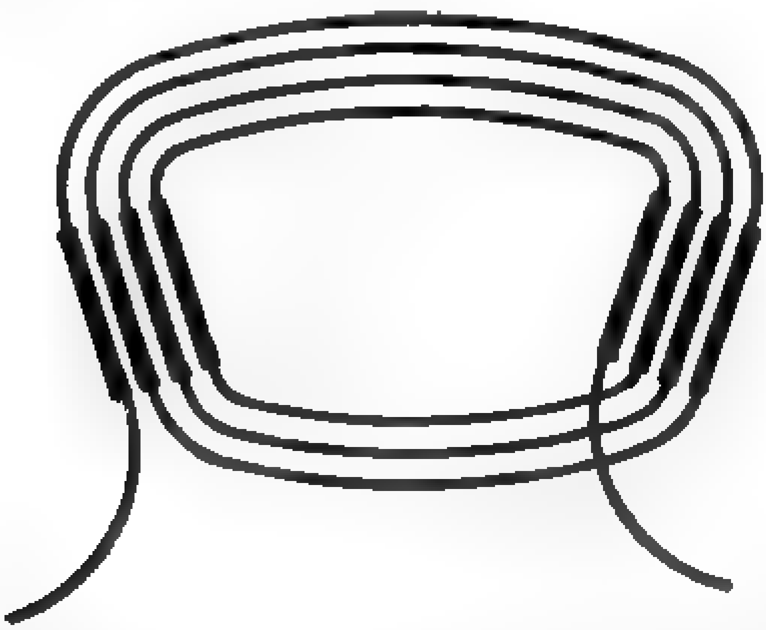


FIG. 1,569.—Diagram showing a spiral coil. Thus type of coil is one in which each successive turn lies entirely within the previous turn, starting with the outermost turn of the coil. The successive turns of a spiral coil are thus not of the same size, and are not over-lapping as in a "lap" coil.

Spiral Winding.—This is a winding in which "spiral" coils, as shown in fig. 1,560, are used. The spiral form of coil is very extensively used for armature windings of alternators.

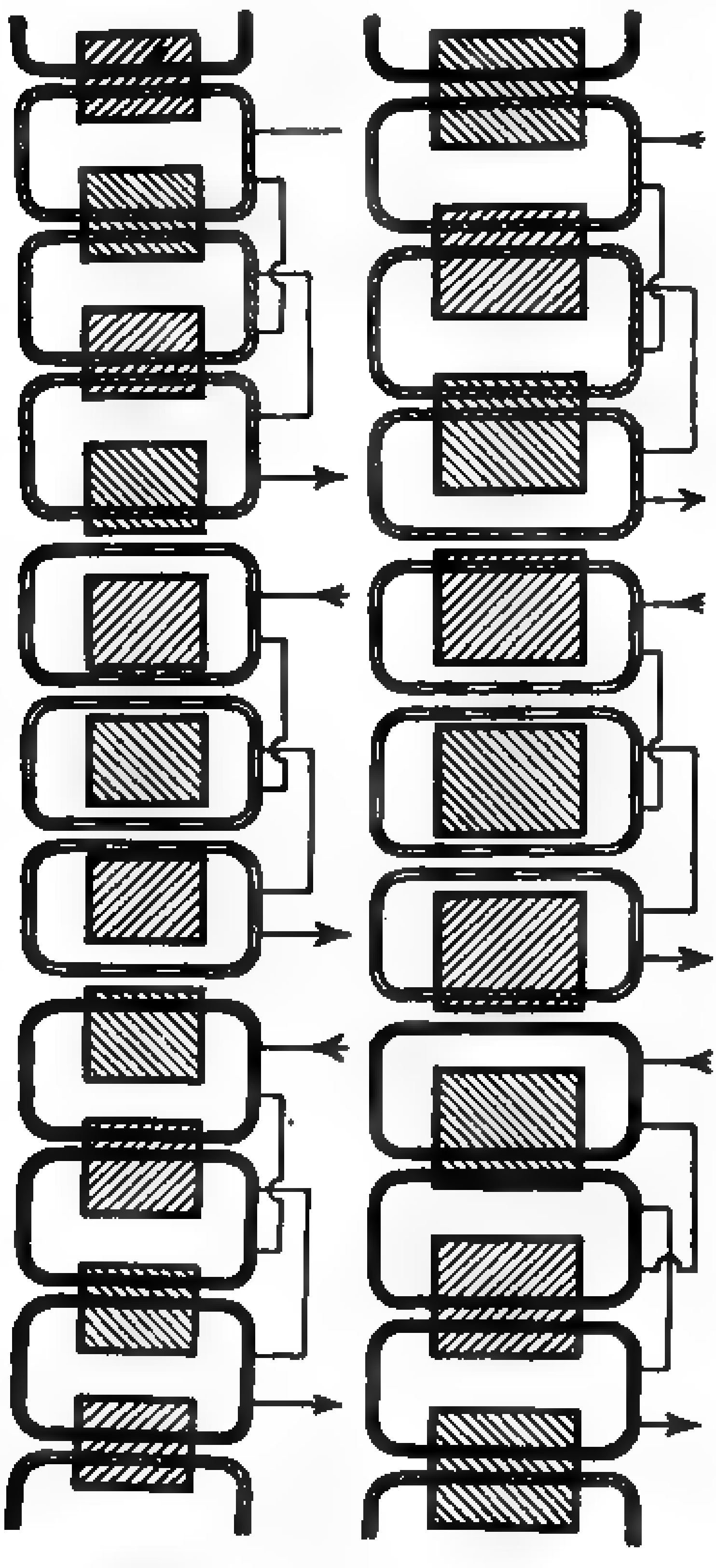
Mummified Winding.—The word *mummified* as applied to a winding is used to express the treatment the coils of the winding receive in the making; that is, when a winding, after being covered with tape or other absorbent material, is saturated in an insulating compound and baked until the whole is solidified it is said *to be mummified.*

Shuttle Winding.—This type of winding consists of a single coil having a large number of turns, wound in two slots spaced 180° apart. It was originally used on Siemens' armature and is now used on magnetos, as shown in figs. 1,459 to 1,461.

Fig. 1,570.—Frame and armature winding of Westinghouse pedestal bearing alternator. Armature frames are of cast iron and ventilated. Interior transverse ribs strengthen the frame and support the core laminations. The armature core is built up of annealed and japanned punched laminations. Armature slots are open. Armature coils are form wound, impregnated, and interchangeable; they are held in place with fiber wedges. Ventilating spaces are provided at intervals in the armature core and also between all coil ends.

Creeping Winding.—Another species of winding, known as a creeping winding is applicable to particular cases.

If three adjacent coils, each having a pitch of 120 electrical degrees, be set side by side, they will occupy the same breadth as 4 poles, and, by repetition, will serve for any machine having a multiple of 4 poles, *but cannot be* used for machines with 6, 10 or 14 poles. *Fig. 1,571 shows this example.*



FIGS. 1,571 and 1,572.—Diagram of creeping windings. Fig. 1,571, three coils subtending four poles; fig. 1,572, nine coils subtending eight poles.

In the same way 9 coils, each of 160 electrical degrees, will occupy the same angular breadth as 8 poles.

Further, 9 coils of 200 electrical degrees will occupy the same angular breadth as 10 poles.

Now of these 9 coils, any three contiguous ones are nearly in phase, if wound alternately clockwise and counterclockwise.

For the 8 pole machine, the phase difference between adjacent coils is 20 degrees.

For the 10 pole machine, the phase difference is also 20 degrees.

The cosine of 20 degrees is .9397, consequently, if 3 adjacent coils be united in series, their joint pressure will be 2.897 multiplied by that of the middle one of the three.

The 9 coils may therefore be joined up in three groups of 3 adjacent coils, for the three phases.

By repetition, th same grouping will for any machine

a multiple of 8 or of 10 poles These two cases are illustrated in figs. 1,572 and 1,573. In the figures, the coils are represented as occupying two slots each, but they might be further distributed.

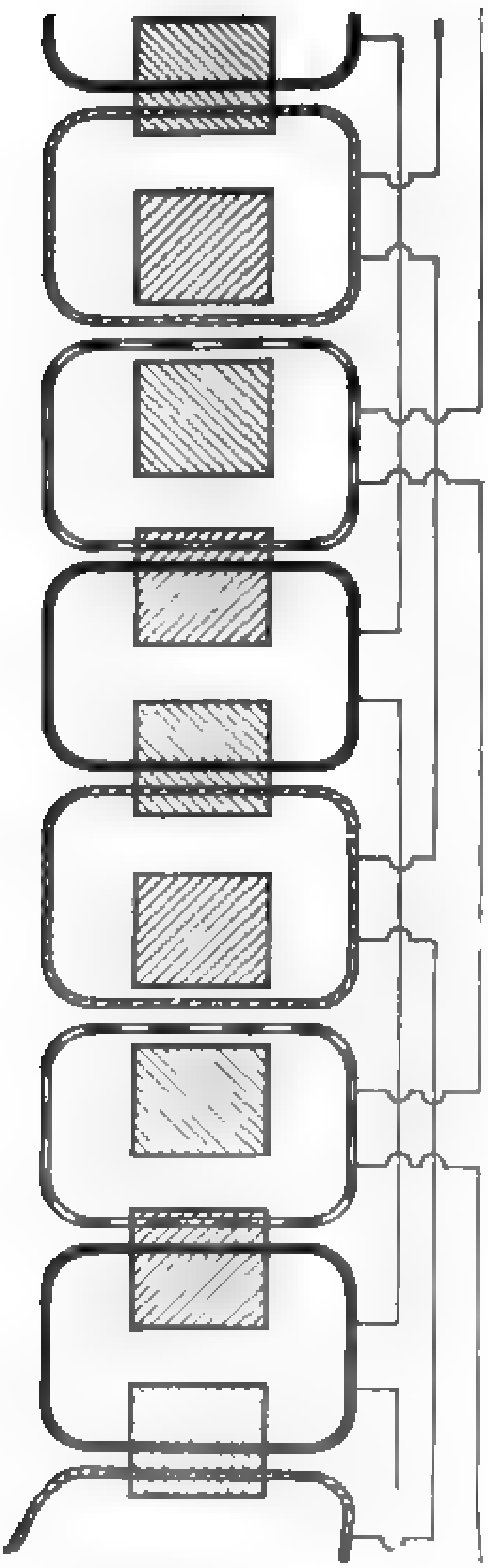
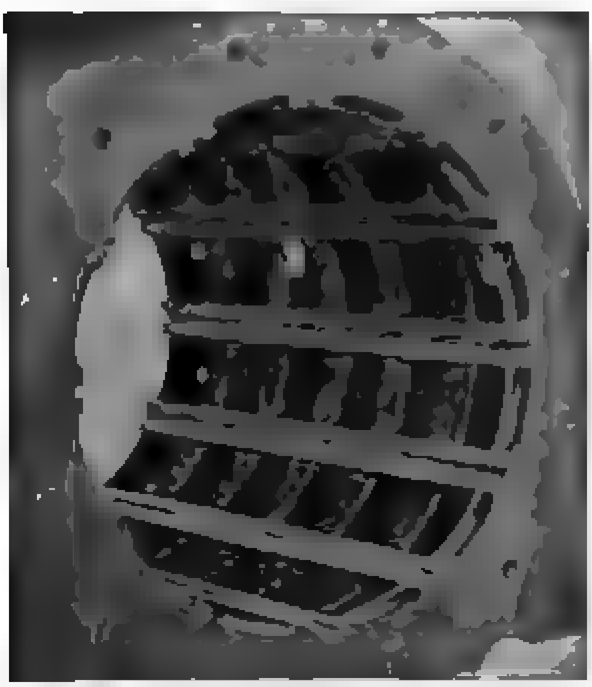


FIG. 1,573.—Developed diagram of creeping winding; nine coils subtending ten poles.

FIG. 1,574.—Triumph pedestal and brush rigging for large revolving field alternators. Carbon brushes are used, carried in box type brush holders. The stand or pedestal here shown is the kind used with the engine and fly wheel types of alternator. The brush studs are mounted on the stand in such a manner that the brushes are easily accessible. The latter carry only the low voltage direct current necessary for exciting the field.

Turbine Alternator Winding.—For the reason that steam turbines run at so much higher speed than steam engines, the construction of armatures and windings for alternators intended to be direct connected to turbines must be quite different from those driven by steam engines. Accordingly, in order that the frequency be not too high, turbine driven alternators must have very few poles—usually two or four, but rarely six.

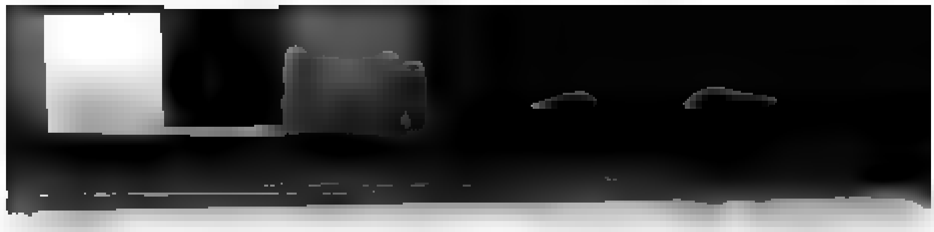


FIGS. 1,575 and 1,576.—Westinghouse turbine alternator armature construction. Fig. 1,575, View showing dovetail grooves in armature casting, fig. 1,576, laminae assembled in dovetail grooves of armature casting.

The following table will show the relation between the revolutions and frequencies for the numbers of poles just designated.

TABLE OF FREQUENCY AND REVOLUTIONS

Frequency	Revolutions		
	2 pole	4 pole	6 pole
25	1,500	750	500
60	3,600	1,800	1,200
100	6,000	3,000	2,000



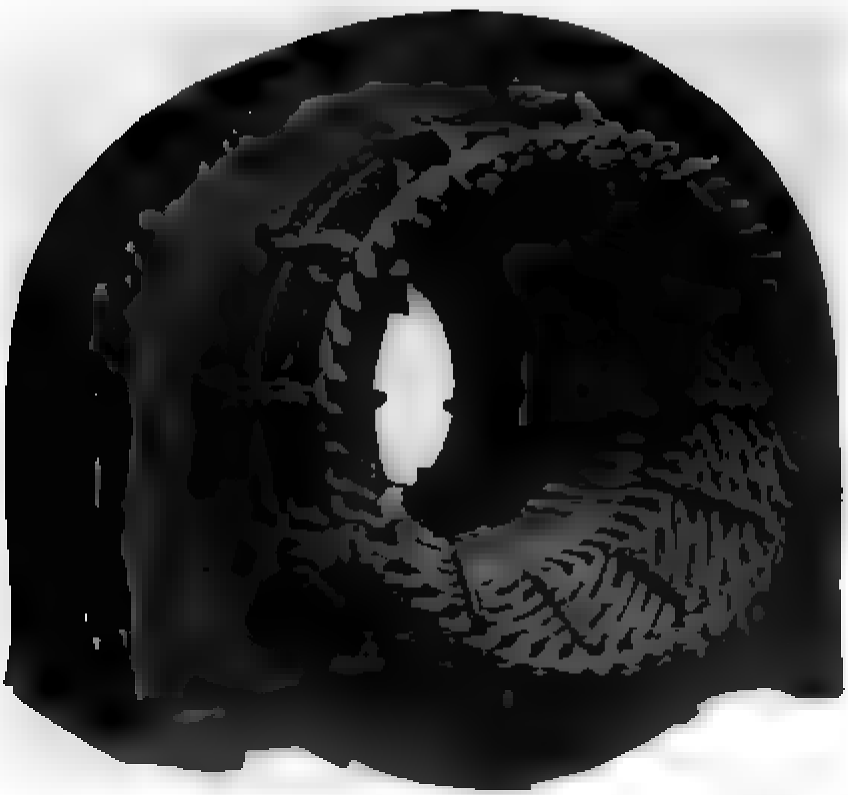


FIG. 1,577.—Armature of Westinghouse turbine alternator with end bells removed showing method of bracing the coil ends.

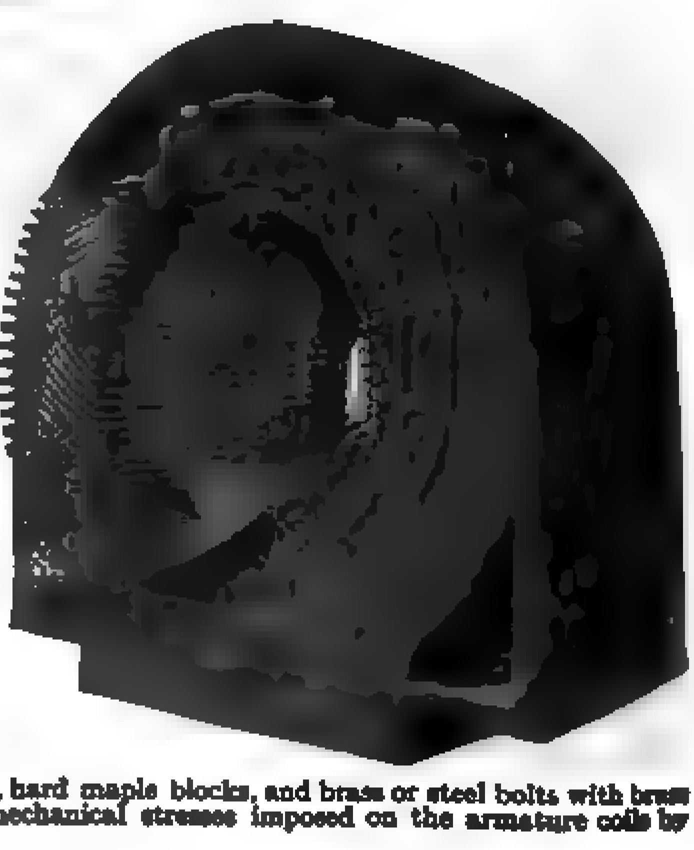


FIG. 1,578.—Stationary armature of Westinghouse turbine alternator with part of the winding in place. Because of the small number of coils in a turbine alternator as compared with a slow speed machine of the same kva. rating, each coil carries a great amount of power on large load, particularly at times of short circuits or grounds on the external circuit. The "throw" of the coils is large, leaving a considerable part of the winding in the end turns unsupported by the armature core For these reasons great stresses, which are dangerous, if effective means be not adopted to withstand them, may exist between the coils. The inductors are of such cross section that they can be made rigid and insulated satisfactorily. The end turns are given a fan like form as shown, affording ventilation and effective bracing as shown in fig. 1,577 Cord lashings are, except in the smallest frames, used only for holding in the small spacing blocks between the coils. They are not depended on to support the coils. Malleable iron braces, hard maple blocks, and brass or steel bolts with brass washers are used to withstand the mechanical stresses imposed on the armature coils by external short circuits.

From the table, it is evident that a large number of poles is not permissible, considering the high speed at which the turbine must be run.

FIG. 1,579.—Two pole radial slot field. Radial slot fields are used on very small and very large alternators. The field diameters are so small that the end turns of the winding can be effectively bound into place, such binding being necessary with a radial slot machine. The shaft and disc are a one piece forging of steel.

Ques. How is the high voltage obtained with so few poles?

Ans. There must be either numerous inductors per slot or numerous slots per pole.

FIGS. 1,580 to 1,582.—Westinghouse two pole parallel slot field with ends removed showing construction. The parallel slot design of field construction is used in Westinghouse machines up to 10,000 kva. capacity. In fig. 1,581, the large holes at the end near the circumference of the cylinder are for the accommodation of the bolts that hold the bronze end discs and stub shafts. In winding, the cylinder is mounted on a horizontal turntable that rotates in a horizontal plane. The copper strap field coil winding is wound turn by turn under pressure and strip insulation is wound in between. When completed the turns are held rigidly in position with heavy brass wedges. An end disc made of bronze holds the stub shaft and is bolted to each end of the steel center. When the leads are attached to the collector rings the field is complete.

Ques. What form of armature is generally used?

Ans. A stationary armature.

Ques. What difficulty is experienced with revolving armatures?

Ans. The *centrifugal force* being considerable on accou-

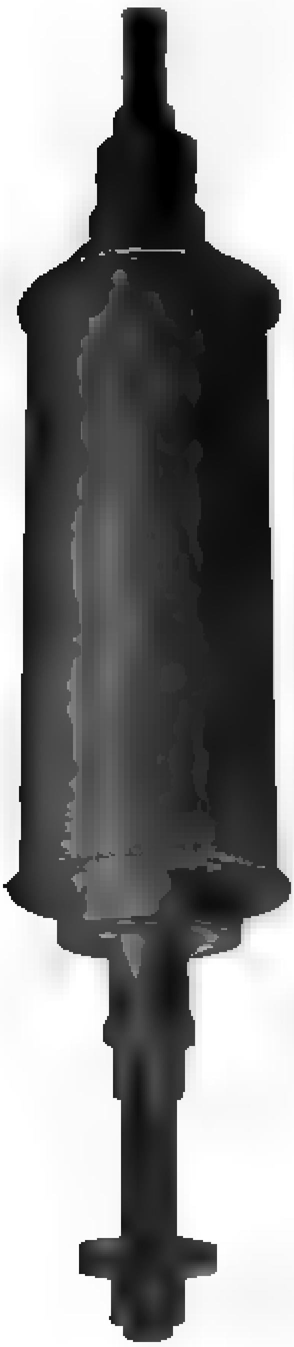


FIG. 1,583.—Westinghouse two pole parallel slot turbine alternator field.

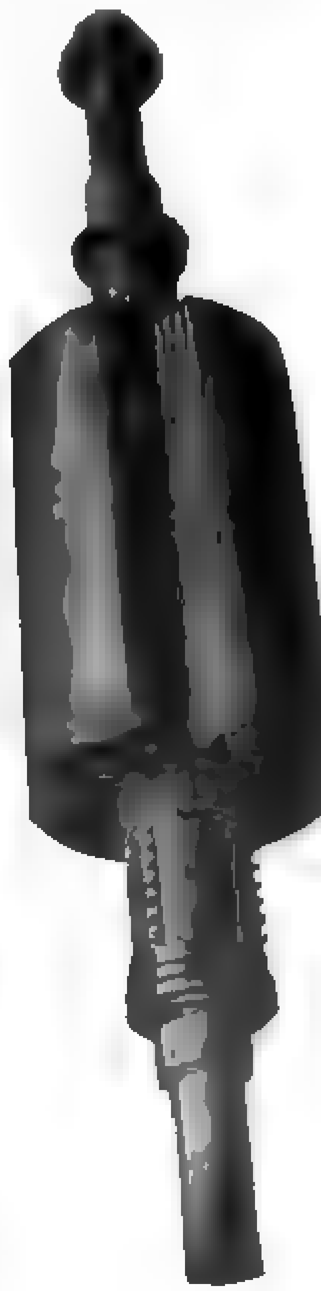


FIG. 1,584.—Westinghouse four pole parallel slot turbine alternator field.

of the high speed, requires specially strong construction to resist it, consequently closed or nearly closed slots must be used.

Ques. How is the design of the rotor modified so as to reduce the centrifugal force?

Ans. It is made long and of small diameter.

Some examples of revolving fields are shown in figs. 1,579 to 1,584. Figs. 1,577 and 1,578 show some construction details of a stationary armature of turbine alternator.

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HAWKINS ELECTRICAL GUIDE

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A PRACTICAL TREATISE

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GUIDE NO. 6.

CHAPTER LI

ALTERNATING CURRENT MOTORS

The almost universal adoption of the alternating current system of distribution of electrical energy for light and power, and the many inherent advantages of the alternating current motor, have created the wide field of application now covered by this type of apparatus.

As many central stations furnish only alternating current, it has become necessary for motor manufacturers to perfect types of alternating current motor suitable for all classes of industrial drive and which are adapted for use on the kinds of alternating circuit employed. This has naturally resulted in a multiplicity of types and a classification, to be comprehensive, must, as in the case of alternators, divide the motors into groups as regarded from several points of view. Accordingly, alternating current motors may be classified:

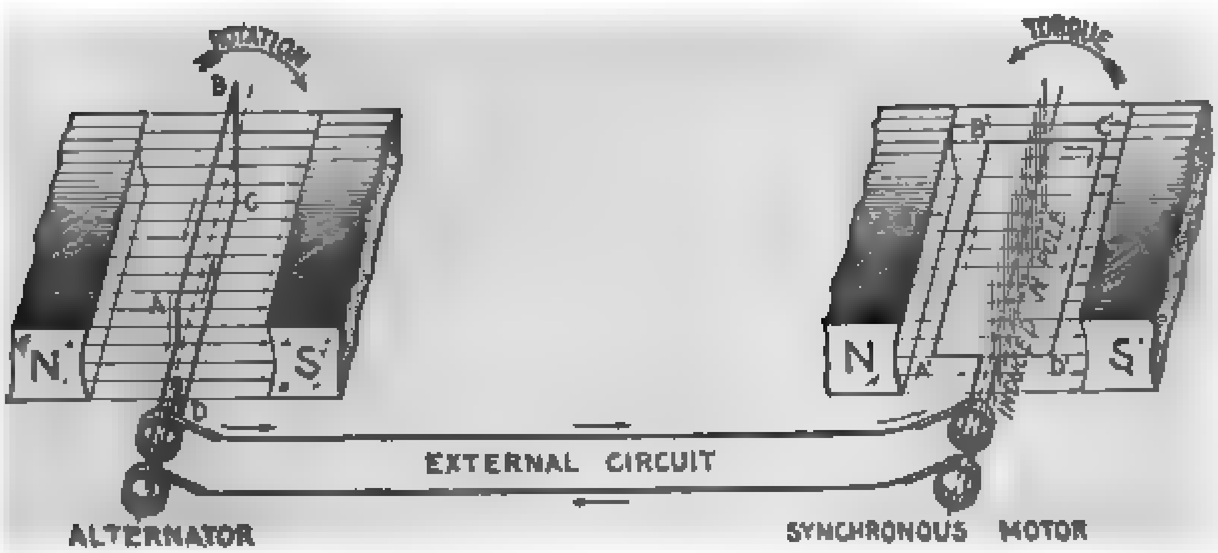
1. With respect to their principle of operation, as

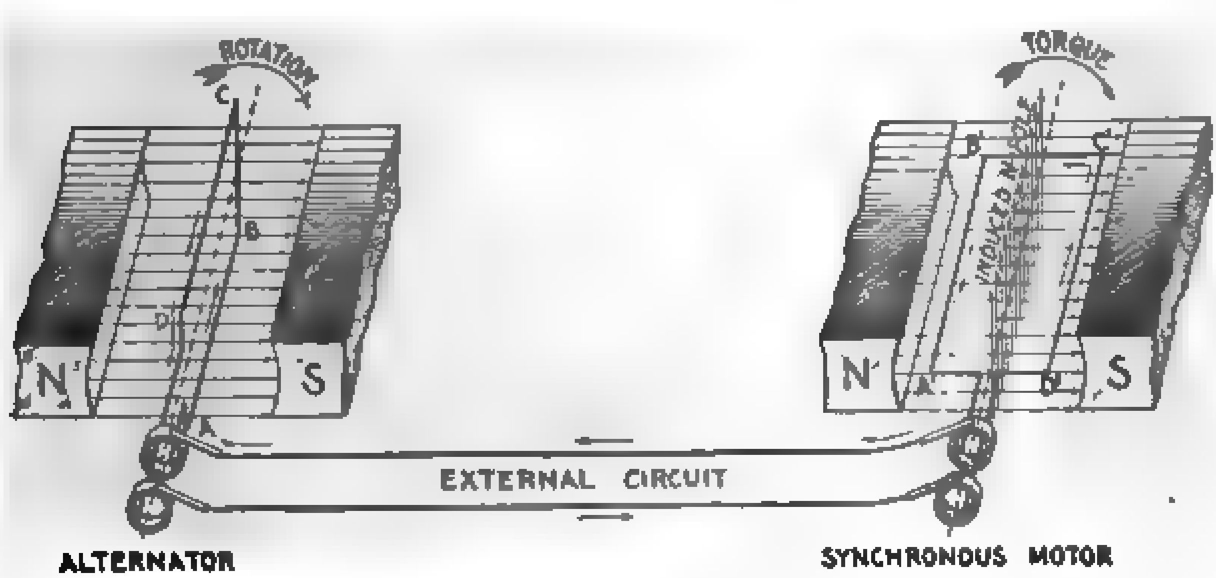
   a. SYNCHRONOUS MOTORS;
   b. ASYNCHRONOUS MOTORS:

      1. **Induction motors;**
      2. **Commutator motors** { *series;* *compensated;* *shunt;* **repulsion.**

2. With respect to the current as

   a. Single phase;
   b. Polyphase;





FIGS. 1,585 to 1,588.—Synchronous motor principles: I. *A single phase synchronous motor is not self-starting.* The figures show an elementary alternator and an elementary synchronous motor, the construction of each being identical as shown. If the alternator be started, during the first half of a revolution, beginning at the initial position ABCD, fig. 1,585, current will flow in the direction indicated by the arrows, passing through the external circuit and armature of the motor, fig. 1,586, inducing magnetic poles in the latter as shown by the vertical arrows. These poles are attracted by unlike poles of the field magnets, which tend to turn the motor armature in a counter-clockwise direction. Now, before *the torque thus set up has time to* overcome the inertia of the motor armature *and cause it to rotate, the alternator armature has completed the half revolution*, and beginning the second half of the revolution, as in fig. 1,587, *the current is reversed* and consequently *the induced magnetic poles in the motor armature are reversed also.* This tends to rotate the armature in the reverse direction, as in fig. 1,588. *These reversals of current occur with such frequency that the force* does not act long enough *in either direction to* overcome the inertia *of the armature; consequently it remains at rest*, or to be *exact, it* vibrates. Hence, a single phase synchronous motor must be started by some *external force* and *brought up to a speed that gives the same frequency as the alternator before it will operate. A single phase synchronous motor* then, is not self-starting, which is *one of its* disadvantages; the reason it will operate after being speeded up to synchronism with the alternator and then connected in the circuit is explained in figs. 1,589 to 1,592.

3. With respect to speed, as
   - *a.* Constant speed;
   - *b.* Variable speed.

4. With respect to structural features, as
   - *a.* Enclosed;
   - *b.* Semi-enclosed;
   - *c.* Open;
   - *d.* Pipe ventilated;
   - *e.* Back geared;
   - *f.* Skeleton frame;
   - *g.* Riveted frame;
   - *h.* Ventilated; etc.

Of the above divisions and sub-divisions some are self-defining and need little or no explanation; the others, however, will be considered in detail, with explanations of the principles of operation and construction.

Synchronous Motors.—The term "synchronous" means *in unison*, that is, *in step*. A so called synchronous motor, then, as generally defined, *is one which rotates in unison or in step with the phase of the alternating current which operates it.*

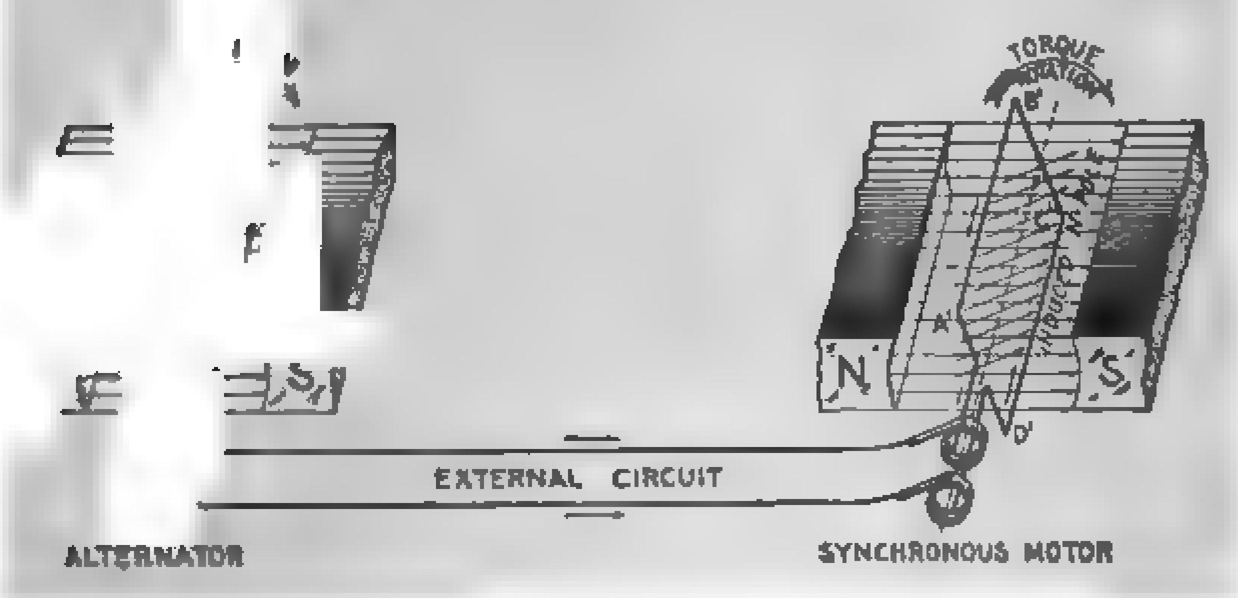
Strictly speaking, however, it should be noted that this condition of operation is only approximately realized as will be later shown.

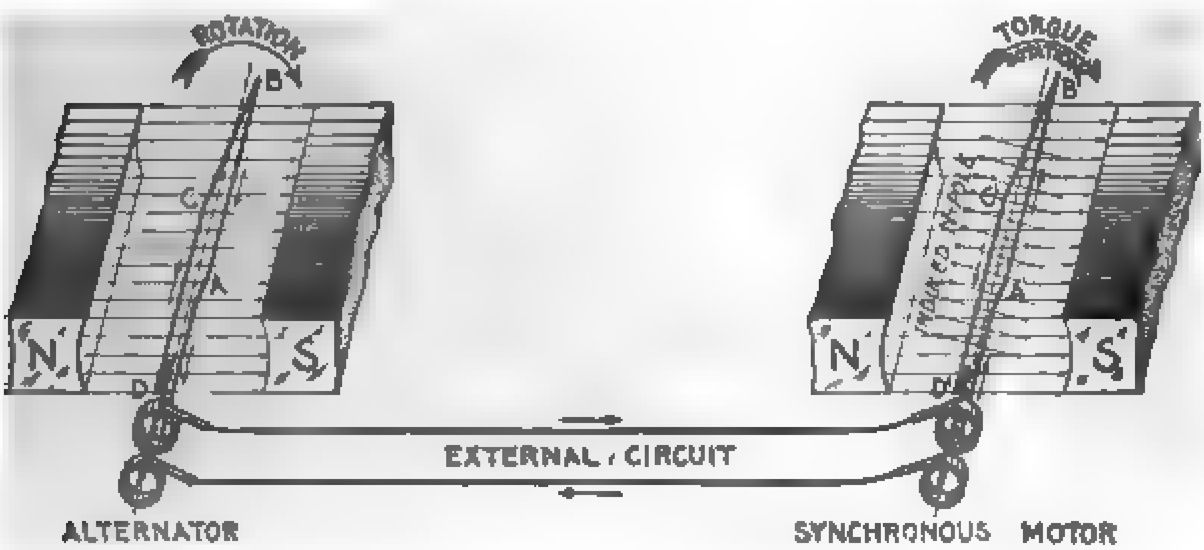
Any single or polyphase alternator will operate as a synchronous motor when supplied with current at the same pressure and frequency as it produces as a generator, the essential condition, in the case of a single phase machine, being that it be speeded up to so called synchronism before being put in the circuit.

In construction, synchronous motors are almost identical with the corresponding alternator, and consist essentially of two elements:

1. An armature,

2. A field.

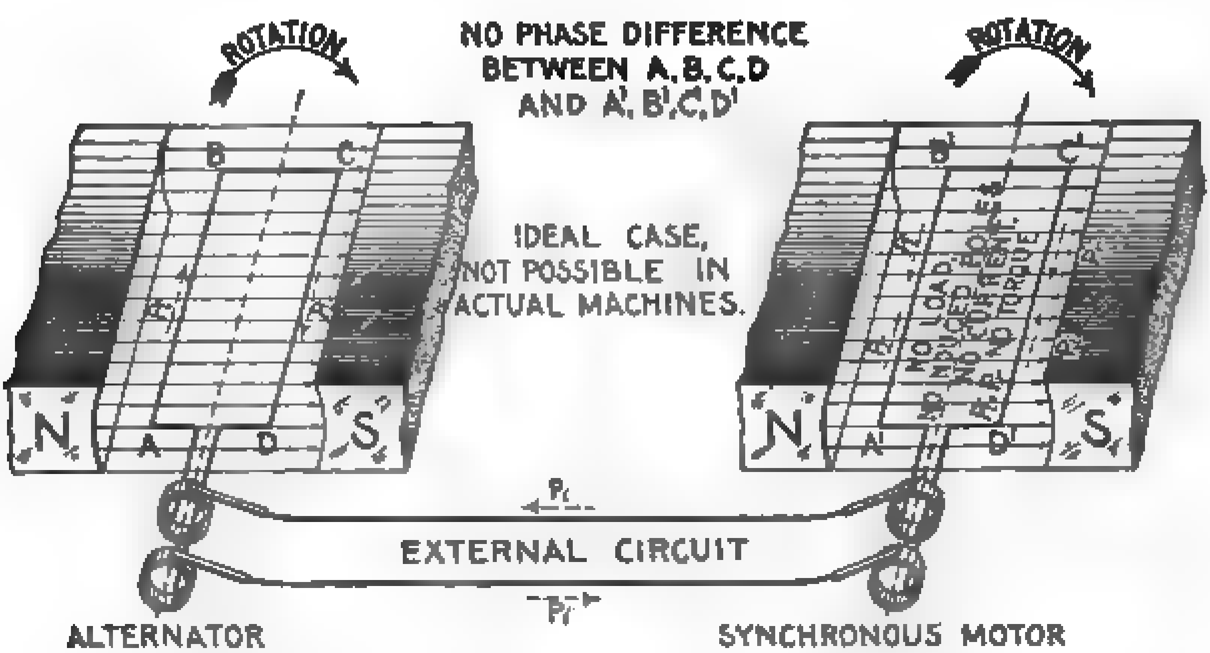




Figs. 1,589 to 1,592.—Synchronous motor principles: II. *The condition necessary for synchronous motor operation is that the motor be speeded up until it rotates in synchronism, that is, in step with the alternator.* This means that the motor must be run at the same frequency as the alternator (not necessarily at the same speed). In the figures it is assumed that the motor has been brought up to synchronism with the alternator and connected in the circuit as shown. In figs. 1,589 and 1,590 the arrows indicate the direction of the current for the armature position shown. The current flowing through the motor armature induces magnetic poles which are attracted by the field poles, thus producing a torque in the direction in which the armature is rotating. After the alternator coil passes the vertical position, the current reverses as in fig. 1,591, and the current flows through the motor armature in the opposite direction, thus reversing the induced poles as in fig. 1,592. *This brings like poles near each other, and since the motor coil has rotated beyond the vertical position* the repelling action *of the* like poles, and also the attraction of unlike poles, *produces a torque acting in the direction in which the motor is rotating.* Hence, when the two armatures move synchronously, the torque produced by the action of the induced poles upon the field poles is always in the direction in which the motor is running, and accordingly, tends to keep it in operation.

either of which may revolve. The field is separately excited with direct current.

The principles upon which such motors operate may be explained by considering the action of two elementary alternators

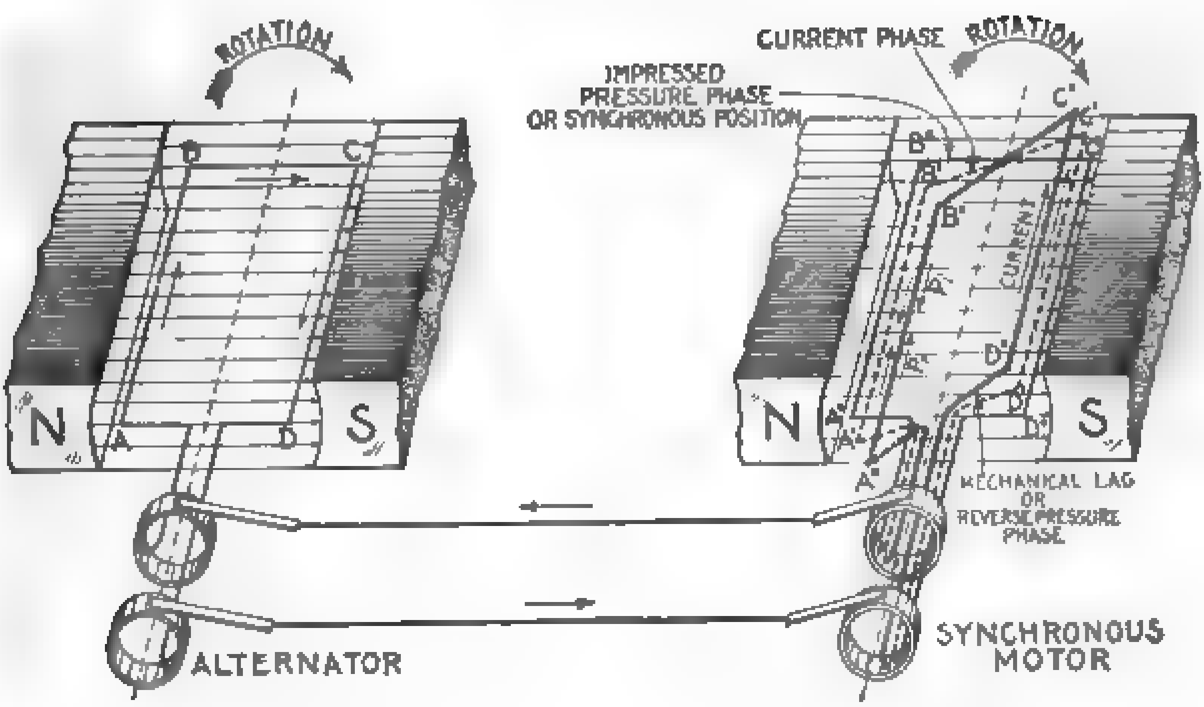


FIGS. 1,593 and 1,594.—Synchronous motor principles: III. *The current which flows through the armature of a synchronous motor is that due to the* **effective** *pressure.* Since the motor rotates in a magnetic field, a pressure is induced in its armature in a direction opposite to that induced in the armature of the alternator, and called the *reverse pressure*, as distinguished from the pressure generated by the alternator called the *impressed pressure*. *At any instant, the pressure available to cause current to flow through the two armatures, called the* **effective pressure**, *is equal to the difference between the pressure generated by the alternator or* **impressed pressure** *and the* **reverse pressure** *induced in the motor.* Now if the motor be perfectly free to turn, that is, without load or friction, the reverse pressure will equal the impressed pressure and no current will flow. This is the case of real synchronous operation, that is, not only is the frequency of motor and alternator the same, but the coils rotate without phase difference. In figs. 1,593 and 1,594, the impressed and reverse pressures are represented by the dotted arrows P_i and P_r, respectively. Since in this case these opposing pressures are equal, the resultant or effective pressure is zero; hence, there is no current. *In actual machines this condition is impossible*, because even if the motors have no external load, there is always more or less friction present; hence, in operation there must be more or less current flowing through the motor armature to induce magnetic poles so as to produce sufficient torque to carry the load. The action of the motor in automatically adjusting the effective pressure to suit the load is explained in figs. 1,595 and 1,596.

connected in circuit, as illustrated in the accompanying illustrations, one alternator being used as a generator and the other as a *synchronous motor*.

Suppose the motor, as in figs. 1,585 and 1,586, be at rest w

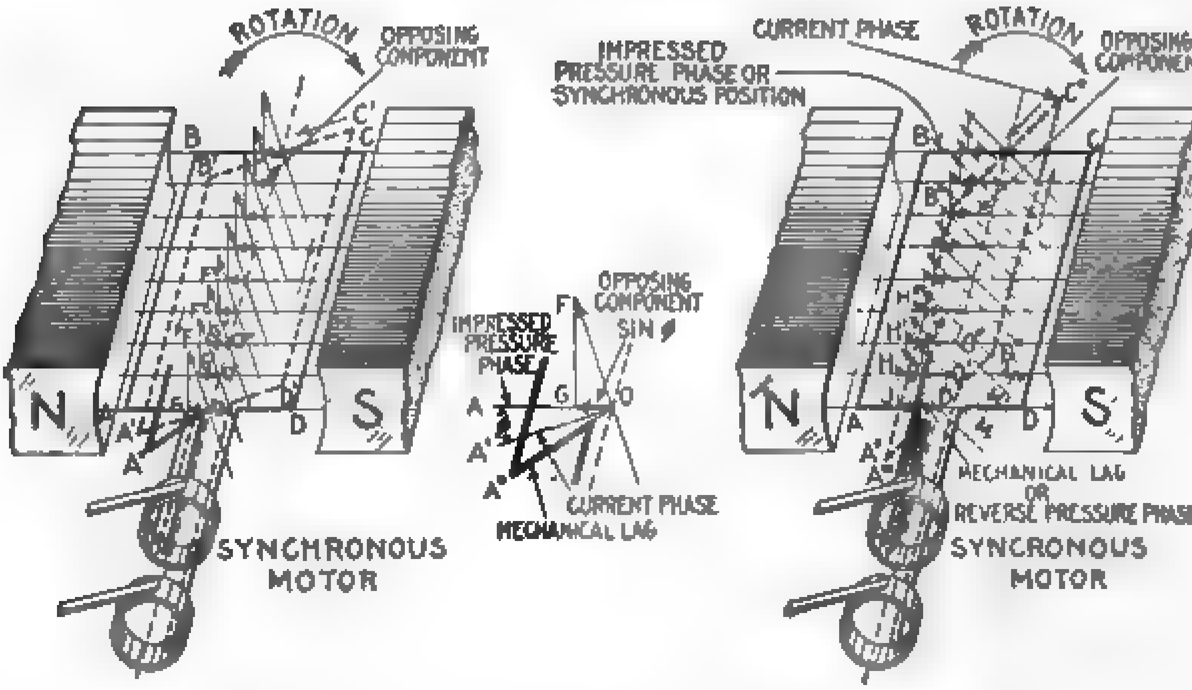
it is connected in circuit with the alternator. The alternating current will flow through the motor armature and produce a reaction upon the field tending to rotate the motor armature first in one direction, then in another.



FIGS. 1,595 and 1,596. Synchronous motor principles: IV—*A synchronous motor adjusts itself to changes of load by changing the phase difference between current and pressure.* If there be no load and no friction, the motor when speeded up and connected in the circuit, will run in true synchronism with the alternator, that is, at any instant, the coils A B C D and A°B°C°D° will be in parallel planes. When this condition obtains, no current will flow and no torque will be required (as explained in figs. 1,593 and 1,594). If a load be put on the motor, the effect will be to cause A°B°C°D° to lag behind the alternator coil to some position A″B″C″D″ and current to flow. The reverse pressure will lag behind the impressed pressure equally with the coil, and the current which has now started will ordinarily take an intermediate phase so that it is **behind** *the impressed pressure but* **in advance** *of the reverse pressure.* These phase relations may be represented in the figure by the armature positions shown, viz.: 1, the synchronous position A°B°C°D° representing the impressed pressure, 2, the intermediate position A′B′C′D′, the current, 3, the actual position A″B″C″D″ (corresponding to mechanical lag), the reverse pressure. From the figure it will be seen that the current phase represented by A′B′C′D′ is in advance of the reverse pressure phase represented by A″B″C″D″. Hence, by **armature reaction,** *the current leading the reverse pressure weakens the motor field and reduces the reverse pressure,* thus establishing equilibrium between current and load. As the load is increased, the mechanical lag of the alternator coil becomes greater and likewise the current lead with respect to the reverse pressure, which intensifies the armature reaction and allows more current to flow. In this way equilibrium is maintained for variations in load within the limits of zero and 90° mechanical lag. The effect of armature reaction on motors is just the reverse to its effect on alternators, which results *in marked* automatic adjustment between the machines especially when a single motor *is operated from an alternator* of about the same size. In other words, the current *which weakens or strengthens* the motor field, strengthens or weakens respectively the *alternator field* as the load is varied.

Because of the very rapid reversals in direction of the torque thus set up, there is not sufficient time **to overcome the inertia of the armature** *before the current reverses and produces a torque in the opposite direction, hence, the armature remains stationary or, strictly speaking,* **it vibrates.**

Now if the motor armature be first brought up to a speed corresponding in frequency to that of the alternator before connecting the motor



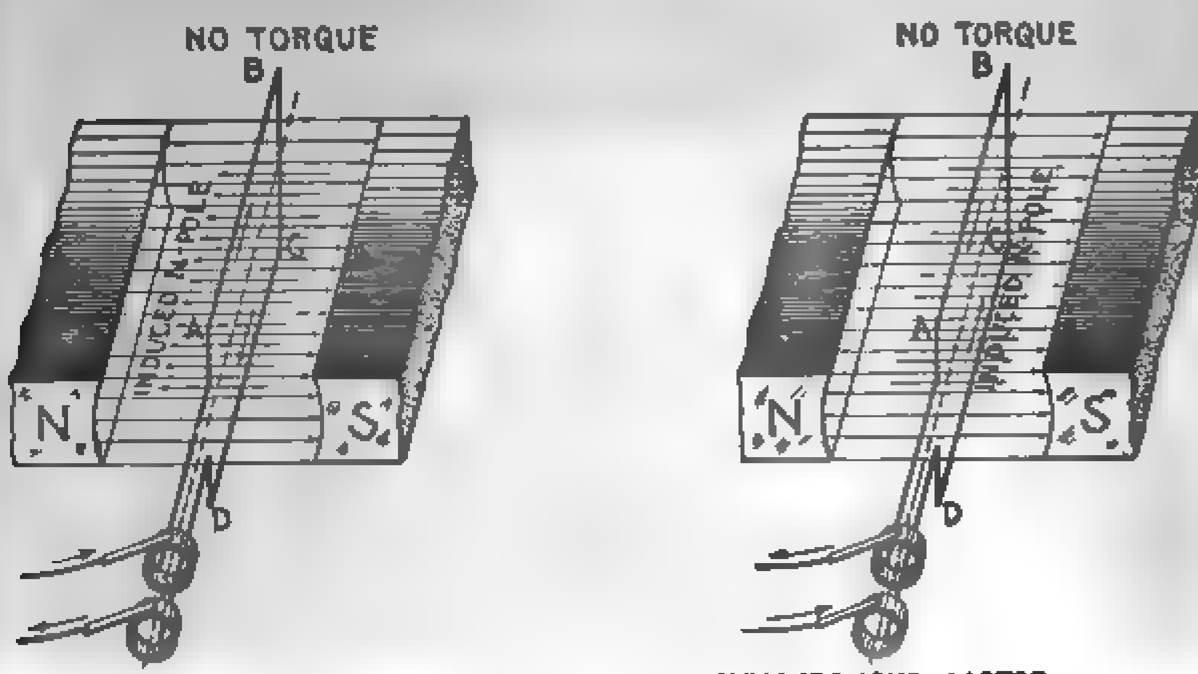
FIGS. 1,597 and 1,598.—Synchronous motor principles: V. *The effectiveness of armature reaction in weakening the field is proportional to the* **sine of the angle** *by which the current lags behind the impressed pressure.* If a motor be without load or friction, its armature will revolve synchronously (in parallel planes) with the alternator armature. In the figures let ABCD represent an instantaneous position of the motor armature when this condition obtains; it will then represent the phase relationship of impressed and reverse pressures for the same condition of no load, no friction, operation. *Now,* **if a light load be placed on the motor** for the same instantaneous position of alternator armature, **the motor coil will drop behind to some position as** A'', fig. 1.597 (part of the coil only being shown). The reverse pressure will also lag an equal amount and its phase with respect to the impressed pressure will be represented by A''. The armature current will ordinarily take an intermediate phase, represented by coil position A'B'C'D', inducing a field strength corresponding to the 9 lines of force OF, O F', etc. *The current being* **in advance** *of the phase of the reverse pressure A'', the armature reaction* **weakens** *the field*, thus reducing the reverse pressure and allowing the proper current to flow to balance the load. The amount by which the field is weakened may be determined by resolving the induced magnetic lines OF, O'F', O''F'', etc., into components OG, GF. O'G', G'F', O''G'', G''F'', etc., respectively parallel and at right angles to the lines of force of the main field. Of these components, the field is weakened only by OG, O'G', O''G'', etc. Since by construction, angle OPG = AOA', and calling OF unity length, OG = sine of angle by which the current lags behind the impressed pressure. The construction is shown better in the enlarged diagram. For a heavier load the armature coil will drop back further to some position as A''', fig. 1,508, and the lag of the current increase to some intermediate phase as A''B'' C''D''. By similar construction it is seen that the component OG (fig. 1,597) has increased to OJ (fig. 1,598), this component thus further *weakening* the main field, by an amount proportional to **the sine of** *the angle by which the current lags behind the impressed pressure.* The increased current *which is now permitted to flow*, causes the induced field to be strengthened (as indicated *by the dotted magnetic lines* M, M', M'', etc.), thus increasing the torque to balance *the additional load.*

in the circuit, the armature will continue revolving at the same frequency as the alternator.

The armature continues revolving, because, **at synchronous speed,** *the field flux and armature current are always in the same relative position,* producing a torque which always pulls the armature around in the same direction.

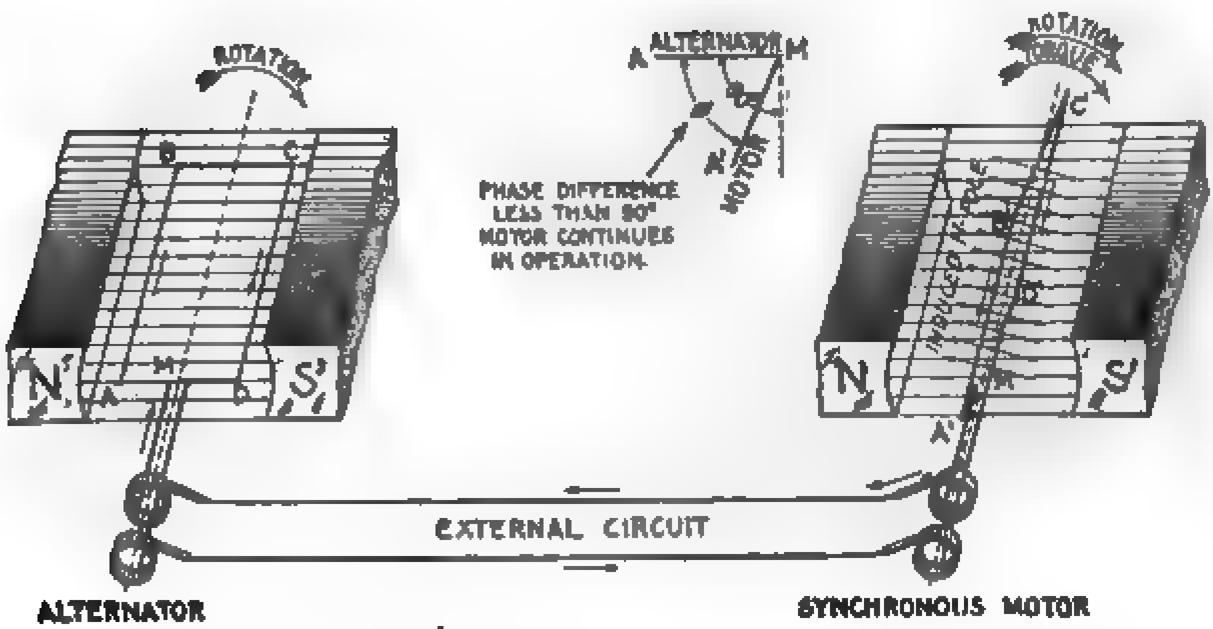
A polyphase synchronous motor is self starting, because, before the current has died out in the coils of one phase, it is increasing in those of the other phase or phases, so that there is always some turning effort exerted on the armature.

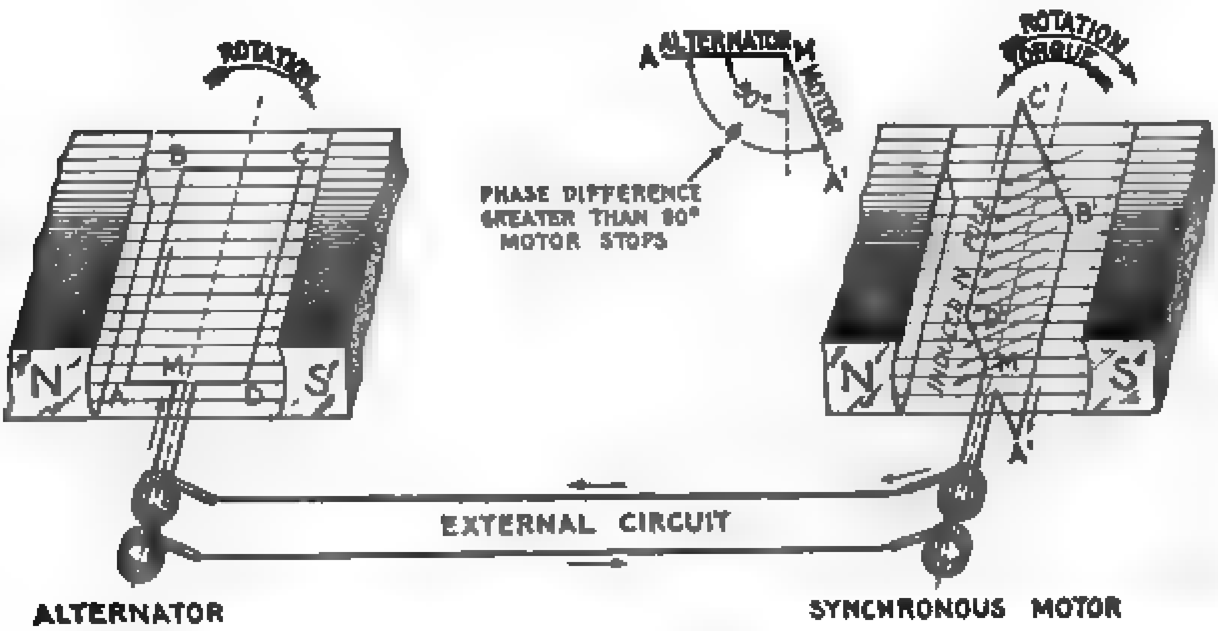
The speed of a synchronous motor is that at which it would have to run, if driven as an alternator, to deliver the number of cycles which is given by the supply alternator.



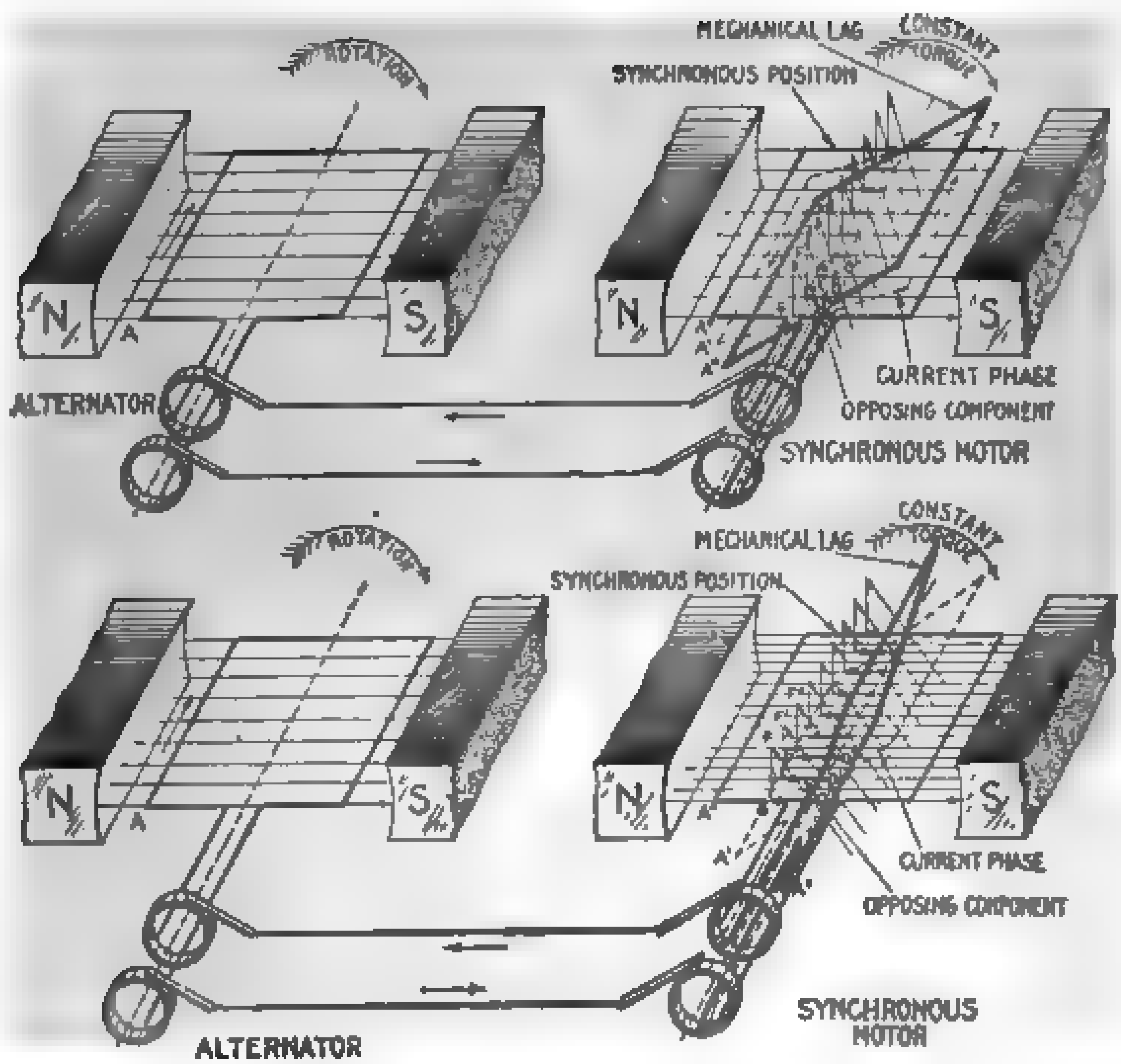
FIGS. 1,599 and 1,600.—Synchronous motor principles: VI. *A single phase synchronous motor has* **"dead centers,"** *just the same as a one cylinder steam engine.* Two diagrams of the motor are here shown illustrating the effect of the current in both directions. When the plane of the coil is perpendicular to the field, the poles induced in the armature are parallel to field for either direction of the current; that is to say, the field lines of force and the induced lines of force acting in parallel or opposite directions, no turning effect is produced, just as in analogy when an engine is on the dead center, the piston rod (field line of force) and connecting rod (induced line of force) being in a straight line, the force exerted by the steam on the piston produces no torque.

For instance, a 12 pole alternator running at 600 revolutions per *minute* will deliver current at a frequency of 60 cycles a second; an *8 pole synchronous* motor supplied from that circuit will run at 900 *revolutions* per minute, which is the speed at which it would have to be *driven as* an alternator to give 60 cycles a second—the frequency of *the 12 pole* alternator.





Figs. 1,601 to 1,604.—Synchronous motor principles: VII. *An essential condition for synchronous motor operation is that the mechanical lag be less than 90°.* Figs. 1,601 and 1,602 represent the conditions which prevail when the lag of the motor armature A'B'C'D' is anything less than 90°. As shown, the lag is almost 90°. The direction of the current and induced poles are indicated by the arrows. *The inclination of the motor coil is such that* **the repulsion of like poles** *produces a torque* **in the direction of rotation,** thus tending to keep motor in operation. Now, in figs. 1,603 and 1,604, for the same position of the alternator coil ABCD, *if the lag be greater than* 90°, the inclination of the motor coil A'B'C'D' is such *that at this instant* **the repulsion of like poles** produces a torque in a direction opposite *to that of* **the rotation,** *thus* **tending to stop the motor.** In actual operation this quickly brings the motor to rest, having the same effect as a strong brake in overcoming the momentum of a revolving wheel.



Figs. 1,605 to 1,608.—Synchronous motor principles: VIII. *If the torque and current through the motor armature be kept constant, strengthening the field will increase the mechanical lag, and the lead of the current with respect to the reverse pressure.* In the figures, let A be an instantaneous position of the alternator coil, A°, synchronous position of motor coil, A', position corresponding to current phase, A'', actual position or mechanical lag of motor coil behind alternator coil necessary to maintain equilibrium. In fig. 1,606, let A' and A'' represent respectively the relation of current phase and mechanical lag *corresponding to a* **certain** *load and field strength.* For these conditions OG, O'G', O''G'', etc., will represent the components of the induced lines of force in opposition to the motor field, that is, *they indicate the intensity of the armature reaction at the instant depicted.* Now, assume the field strength to be **doubled**, as in fig. 1,608, *the motor* **load** *and* **current** *being maintained* **constant**. Under these conditions, the armature reaction must be doubled to maintain equilibrium; that is, the components OG, O'G', etc., fig. 1,608, must be twice the length of OG, O'G', etc., fig. 1,605. Also since the current is maintained constant, the induced magnetic lines OF, O'F' are of same length in both figures. Hence, in fig. 1,608 the plane of these components is such that their extremities touch perpendiculars from G, G', etc., giving the other components FG, F'G', etc. The plane A', normal to OF, O'F', etc., gives the current phase. By construction, the phase difference *between A° and A'* is such that sin A°OA' (fig. 1,608) = 2 × sin A°OA' (fig. 1,606). That *is, doubling the field* **strength** causes an increase of current lag such that the sine of the *angle of this lag* is doubled. Since the intensity of the armature reaction depends on the *lead of the current* **with** respect to the reverse pressure, the mechanical lag of the coil must *be increased to some position as A''* (fig. 1,608), such as will give an armature reaction of intensity indicated by the components OG, O'G', etc.

The following simple formula gives the speed relations between generators and motors connected to the same circuit and having different numbers of poles.

$$s = \frac{P \times S}{p}$$

in which

s. Revolutions per minute of the motor;
p. Number of poles of the motor;
S. Revolutions per minute of the alternator;
P. Number of poles of the alternator.

Question. If the field strength of a synchronous motor be altered, what effect does this have on the speed, and why?

Ans. The speed does not change (save for a momentary variation to establish the phase relation corresponding to equilibrium), because the motor has to run at the same frequency as the alternator.

Ques. How does a synchronous motor adjust itself to changes of load and field strength?

Ans. By changing the phase difference between the current and pressure.

If, on connecting a synchronous motor to the mains, the excitation be too weak, so that the voltage is lower than that of the supply, this phase difference will appear resulting in wattless current, since the missing magnetization has, as it were, to be supplied from an external source. A phase difference also appears when the magnetization is too strong.

Ques. State the disadvantages of synchronous motors.

Ans. A synchronous motor requires an auxiliary power for starting, and will stop if, for any reason, the synchronism be destroyed; collecto rings and brushes are required. For some purposes synchronous motors are not desirable, as for driving *shafts in small workshops* having no other power available for *starting, and in* cases where frequent starting, or a strong torq

at star[illegible]cessary. A synchronous motor has a tendency to *hun*[illegible]nd requires intelligent attention; also an exciting current wh[illegible]h must be supplied from an external source.

Ques. State the advantage of synchronous motors.

Ans. The synchronous motor is desirable for large powers where starting under load is not necessary. Its power factor

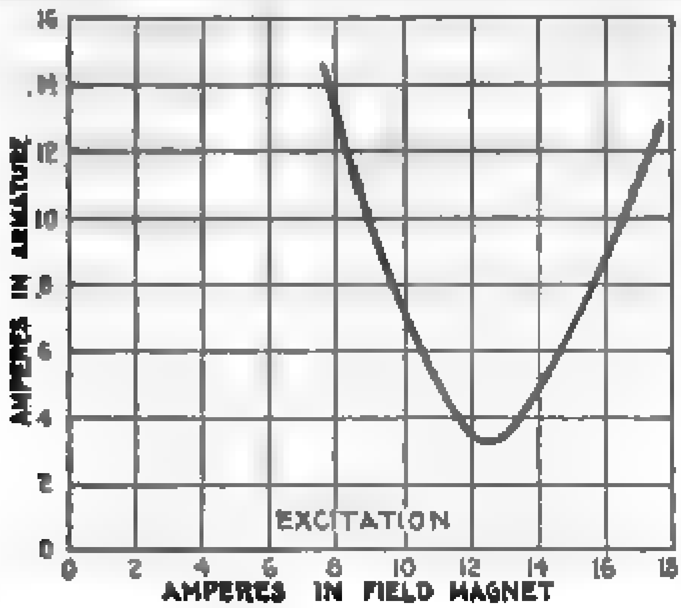


FIG. 1,600.—Diagram illustrating method of representing the performance of synchronous motors. The *V shaped curve* is obtained by plotting the current taken by motor under different degrees of excitation, the power developed by the motor remaining constant. The current may be made to lag or lead while the load remains constant, by varying the excitation. By varying the excitation, a certain value may be reached which will give a minimum current in the armature; this is the condition of unity power factor. If now the excitation be diminished the current will lag and increase in value to obtain the same power; if the excitation be increased the current will *lead* and increase in value to obtain the same power. The results plotted for several values of the excitation current will give the V curve as shown. This is an actual curve obtained by Mordey on a 50 kw. machine running unloaded as a motor. Other curves situated above this one may be obtained for various loadings of the motor.

may be controlled by varying the field strength. The power factor can be made unity and, further, the current can be made to lead the pressure.

A synchronous motor is frequently connected in a circuit solely to *improve the power factor*. In such cases it is often called a "condenser *motor" for the* reason that its action is similar to that of a condenser.

*NOTE.—*See Hunting of synchronous motors, page* 1,280.

The design of synchronous motors proceeds on the same lines as that of alternators, and the question of voltage regulation in the latter becomes a question of power factor regulation in the former.

Ques. For what service are they especially suited?

Ans. For high pressure service.

High voltage current supplied to the armature does not pass through a commutator or slip rings; the field current which passes through slip rings being of low pressure does not give any trouble.

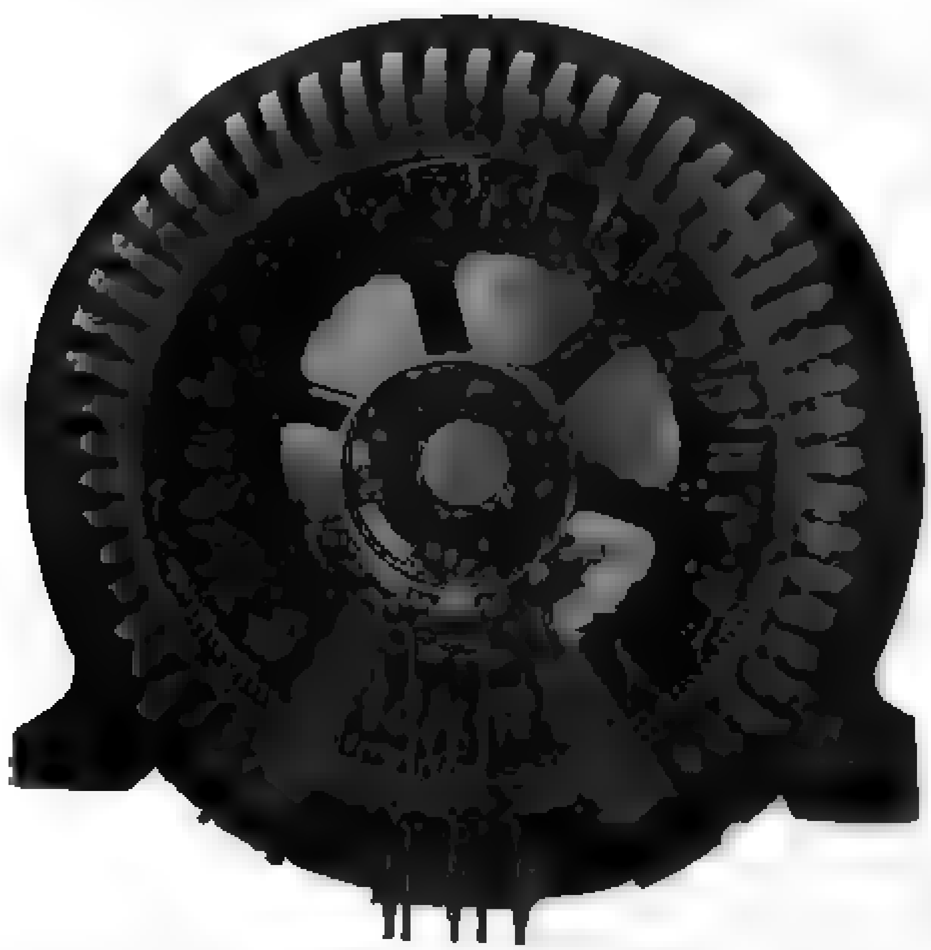


FIG. 1,610.—Westinghouse self-starting synchronous motor. Motors of this type are suitable for constant speed service where starting conditions are moderate, such as driving compressors, pumps, and large blowers. Synchronous motors can be made to operate not only as motors but as synchronous condensers to improve the power factor of the circuit. The field is provided with a combined starting and damper or *amortisseur* winding so proportioned that the necessary starting torque is developed by the minimum current consistent with satisfactory synchronous running without hunting. The armature slots are open and the coils form wound, impregnated, and interchangeable. Malleable iron finger plates at each end of the core support the teeth. Ventilating finger plates assembled with the laminations form air ducts. The frames are of cast iron, box section with openings to ventilation; shoes and slide rails permit adjustment of position. The brush holders are the standard sliding shunt type. Two or more brushes are provided for each ring.

Ques. How do synchronous and induction motors compare as to efficiency?

Ans. Synchronous motors are usually the more efficient.

Hunting of Synchronous Motors.—Since a synchronous motor runs practically in step with the alternator supplying it with current when they both have the same number of poles,

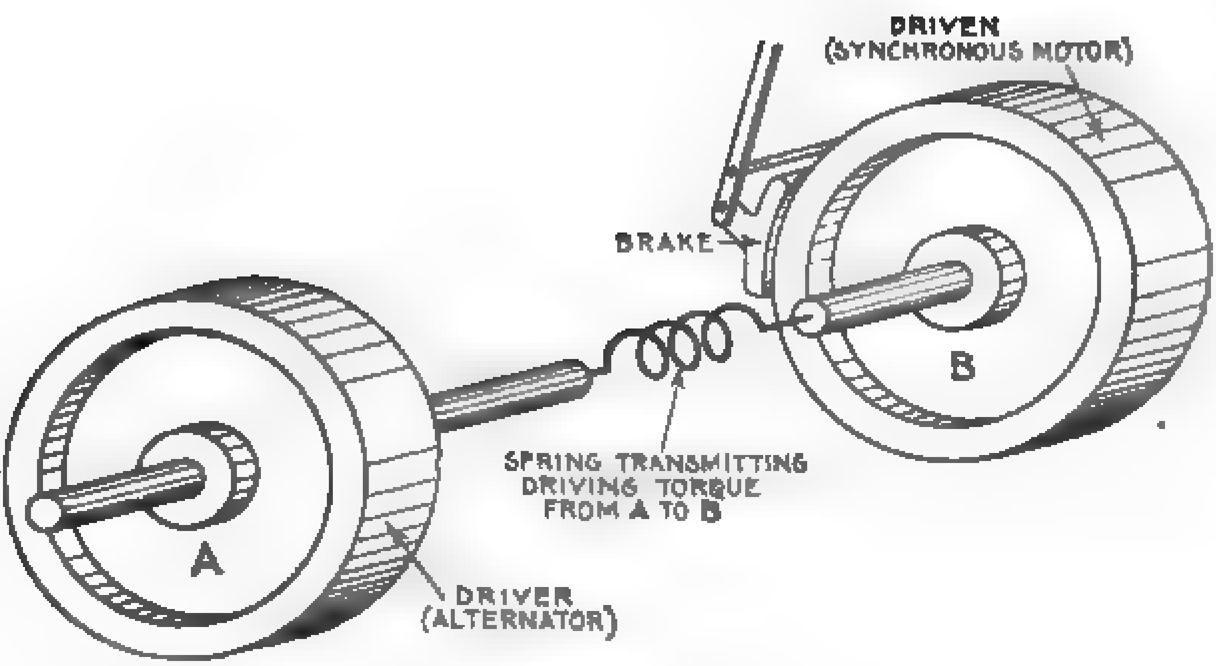


FIG. 1,611.—Mechanical analogy illustrating "hunting." The figure represents two flywheels connected by a spring susceptible to tortion in either direction of rotation. If the wheels A and B be rotating at the same speed and a brake be applied, say to B, its speed will diminish and the spring will coil up, and if fairly flexible, more than the necessary amount to balance the load imposed by the brake; because when the position of proper torque is reached, B is still rotating slightly slower than A, and an additional torque is required to overcome the inertia of B and bring its speed up to synchronism with A. Now before the spring stops coiling up the wheels must be rotating at the same speed. When this occurs the spring has reached a position of too great torque, and therefore exerting more turning force on B than is necessary to drive it against the brake. Accordingly B is accelerated and the spring uncoils. The velocity of B thus oscillates above and below that of A when a load is put on and taken off. Owing to friction, the oscillations gradually die out and the second wheel takes up a steady speed. A similar action takes place in a synchronous motor when the load is varied.

or some multiple of the ratio of the number of poles on each machine, it will take an increasing current from the line as its speed drops behind the alternator, but will supply current to the *line as a generator* if for any reason the speed of the alternator

should drop behind that of the motor, or the current wave lag behind, which produces the same effect, and due to additional self-induction or inductance produced by starting up or overloading some other motor or rotary converter in the circuit.

When the motor is first taking current, then giving current back to the line, and this action is continued periodically, the motor is said to be *hunting*.

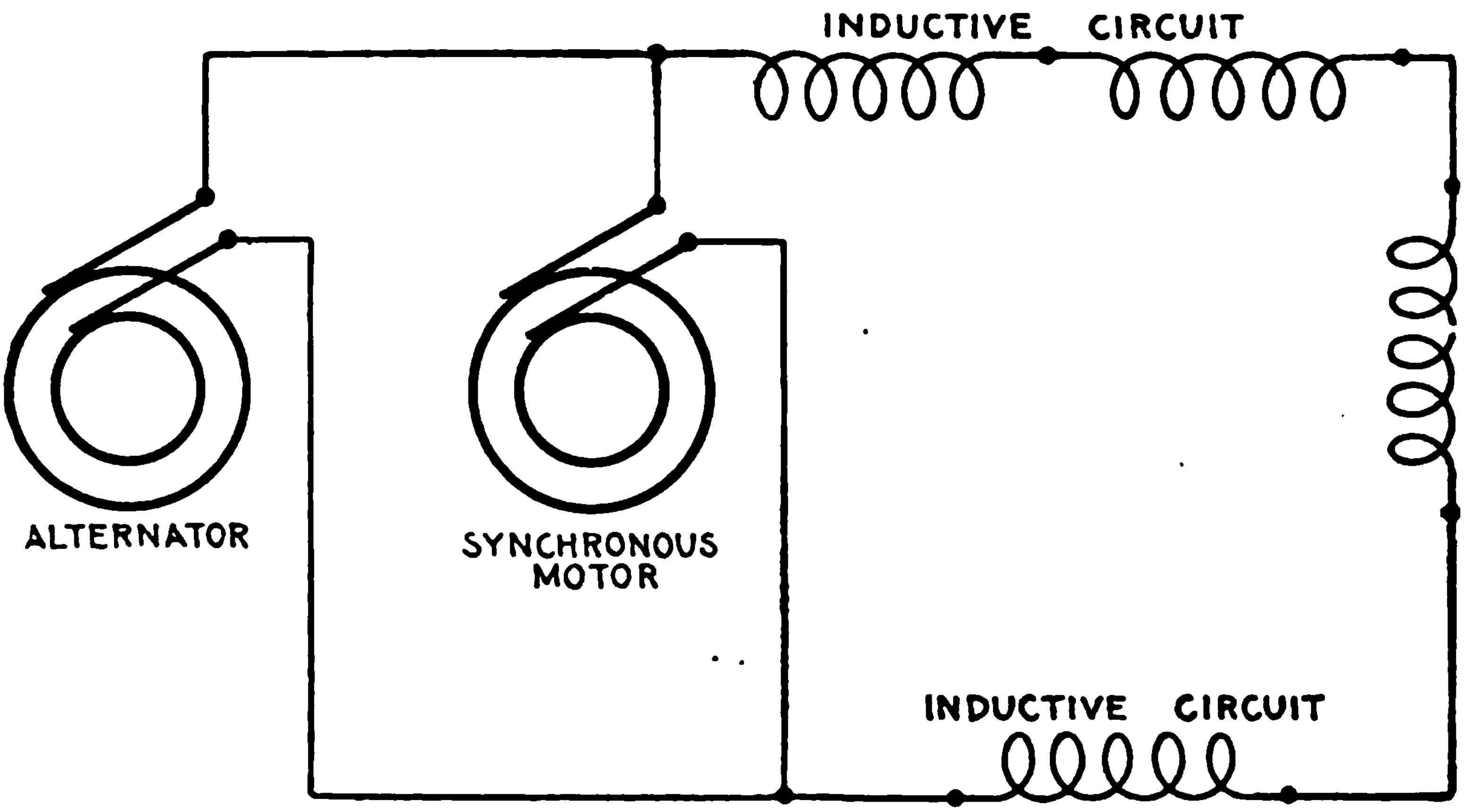


FIG. 1,612.—Diagram illustrating the use of a synchronous motor as a condenser. If a synchronous motor be sufficiently excited the current will lead. Hence, if it be connected across an inductive circuit as in the figure and the field be over excited it will compensate for the lagging current in the main, thus increasing the power factor. If the motor be sufficiently over excited the power factor may be made unity, the minimum current being thus obtained that will suffice to transmit the power in the main circuit. A synchronous motor used in this way is called a *rotary condenser* or *synchronous compensator*. This is especially useful on long lines containing transformers and induction motors.

Ques. What term is applied to describe the behavior of the current when hunting occurs?

Ans. The term *surging* is given to describe the current fluctuations produced by hunting.

The mechanical analogy of hunting illustrated in fig. 1,611 will help to an understanding of this phenomenon. In alternating current circuits a precisely similar action takes place between the alternators and synchronous motors, or even between the alternators themselves.

CHARACTERISTICS OF SYNCHRONOUS MOTORS

Starting.—The motor must be brought up to synchronous speed without load, a *starting compensator* being used. If provided with a self-starting device, the latter must be cut out of circuit at the proper time. The starting torque of motor with self-starting device is very small.

Running.—The motor runs at synchronous speed. The maximum torque is several times full load torque and occurs at synchronous speed.

Stopping.—If the motor receive a sudden overload sufficient to momentarily reduce its speed, it will stop; this may be brought about by momentary interruption of the current, sufficient to cause a loss of synchronism.

Effect upon Circuit.—In case of short circuit in the line the motor acts as a generator and thus increases the intensity of the short circuit. The motor impresses its own wave form upon the circuit. Over excitation will give to the circuit the effect of *capacity*, and under excitation, that of *inductance.*

Power Factor.—This depends upon the field current, wave form and hunting. The power factor may be controlled by varying the field excitation.

Necessary Auxiliary Apparatus.—Power for starting, or if self-starting, means of reducing the voltage while starting; also, field exciter, rheostat, friction clutch, main switch and exciter switch, instruments for indicating when the field current is properly adjusted.

Adaptation.—If induction motors be connected to the same line with a synchronous motor that has a steady load, then the field of the synchronous motor can be over excited to produce a leading current, which will counteract the effect of the lagging currents induced by the induction motors. Owing to the weak starting torque, skilled attendance required, and the liability of the motor to stop under abnormal working *conditions, the* synchronous motor is not adapted to general power distribution, but rather to large units which operate under a steady load and do not require frequent starting and stopping.

FIGS. 1,613 to 1,625.—Disassembled view of Western Electric three phase squirrel cage skeleton frame induction motor.

Induction (Asynchronous) Motors.—*An induction motor consists essentially of an armature and a field magnet, there being, in the simplest and most usual types, no electrical connection between these two parts.**

According to the kind of current that an induction motor is designed to operate on, it may be classified as:

1. Single phase;
2. Polyphase.

The operation of an induction motor depends on the production of a magnetic field by passing an alternating current through field magnets.

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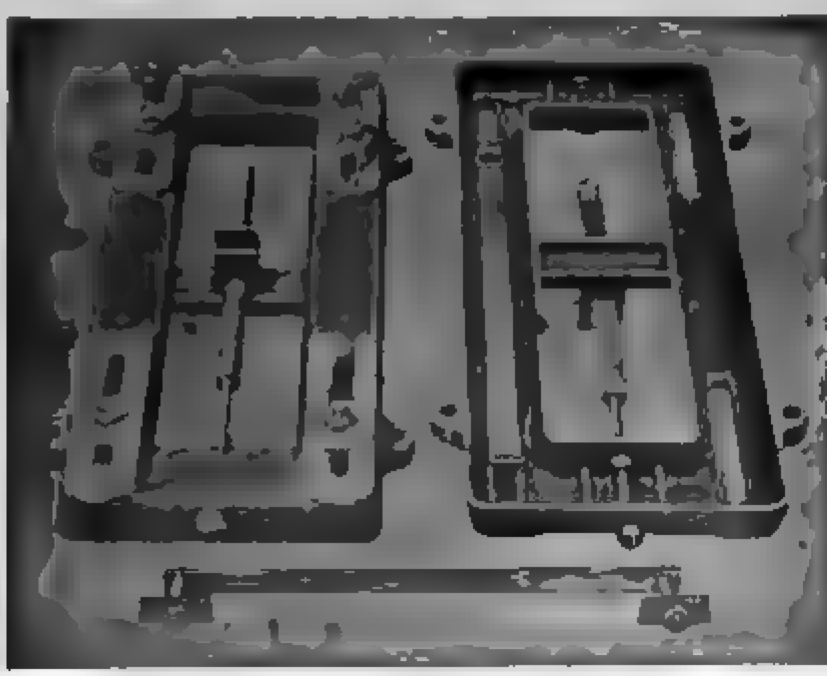
*NOTE.—The author prefers the terms armature and field magnet, instead of "primary," "secondary," "stator," "rotor," etc., as used by other writers, the armature being the part in which currents are induced and the field magnet (or magnets) that part furnishing the field in which the induction takes place.

The character of this field is either

1. Oscillating*, or
2. Rotating,

according as single phase or polyphase current is used.



FIGS. 1,626 to 1,628.—General Electric base construction for polyphase induction motors. The base is made of cast iron. Adjusting gear is provided to slide the motor along the base as shown in the illustrations, the movement being from 6 to 12 inches according to size. With this design of base, motors are securely held in position under all conditions and may be run with an upward pull on the belt. Close fitting guides moving in an accurately machined slot on the base preserve a correct alignment of the motor when adjustment of the latter is required. The same base can be used whether the motor be supported from the wall or ceiling or located on the floor. A single adjusting screw is placed under the center line of the motor frame, which produces an even and balanced draw in either direction on all parts of the motor when the belt tension is altered. This screw can be located at either end of the base. The base can be omitted when the motor is direct connected or when provision for belt adjustment is not required.

Ques. Describe briefly the operation of a single phase motor.

Ans. A single phase current being supplied to the field magnets, an *oscillating field* is set up. A single phase motor is

*NOTE.—"*The word oscillating* is becoming specialized in its application to those currents and fields whose oscillations are being damped out, as in electric 'oscillations.' But for this, *we should have* spoken of an oscillating field."—S. P. Thompson. The author believes the word *oscillating*, notwithstanding its other usage, best describes the single phase field, and should be here used.

not self-starting; but when the armature has been set in motion *by external means*, the reaction between the magnetic field and the induced currents in the armature being no longer zero, a torque is produced tending to turn the armature.

The current flowing through the armature produces an alternating polarity such that the attraction between the unlike armature and field poles is always in one direction, thus producing the torque.

FIG. 1,629.—Richmond three phase induction motor on base fitted with screw adjusting gear for shifting the position of the motor on the base to take up slack of belt.

Ques. Why is a single phase induction motor not self-starting?

Ans. *When the armature is at the rest, the currents induced therein are at a maximum in a plane at right angles to th magnetic field,* hence there is no initial torque to start the mot

[redacted]

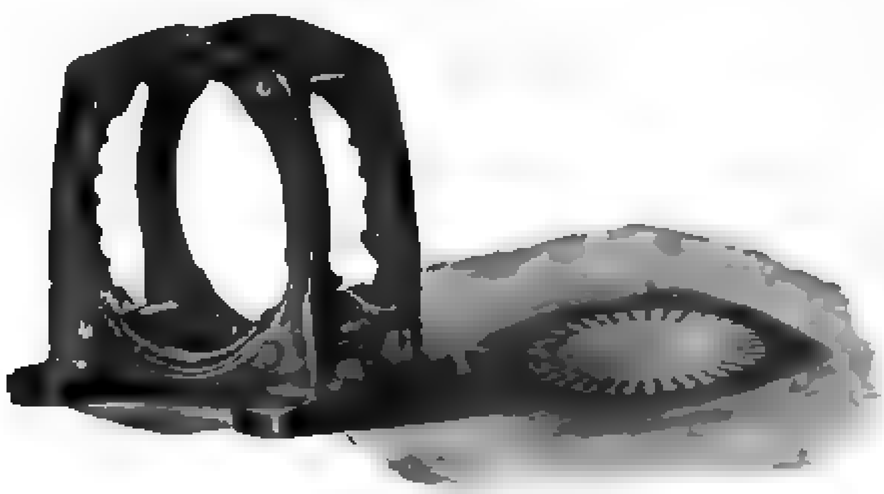
FIGS. 1,630 to 1,641 — Terminals for General Electric polyphase induction motors. In order to prevent any mechanical strain on the leads being transmitted to the motor windings, the terminal cables are clamped in insulated bushings with a connector for each cable.

Ques. What provision is made for starting single phase induction motors?

Ans. Apparatus is supplied for "splitting the phase" (later described in detail) of the single phase current furnished, converting it temporarily into a two phase current, so as to obtain a *rotating field* which is maintained till the motor is brought up to speed. The phase splitting device is then cut out and the motor operated with the *oscillating field* produced by the single phase current.

Ques. Describe briefly the operation of a polyphase induction motor.

Ans. Its operation is due to the production of a *rotating magnetic field* by the polyphase current furnished. This field "rotating" in space about the axis of the armature induces currents in the latter. The reaction between these currents and the rotating field creates a torque which tends to turn the armature, whether the latter be at rest or in motion.



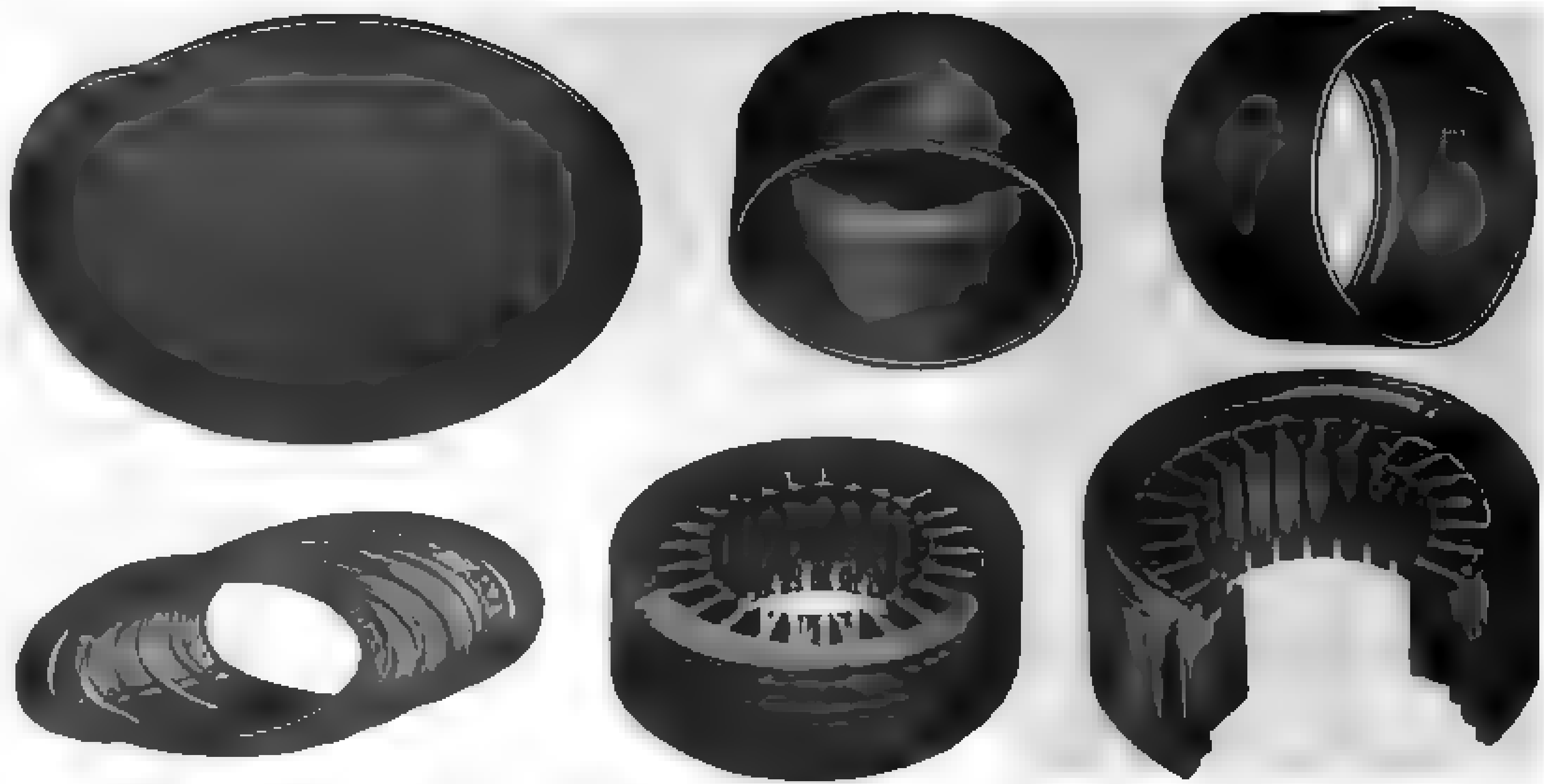
Figs. 1642 and 1643. -Western Electric end flange rivets and punchings of riveted frame induction motor. The riveted frame is constructed of two cast iron flanges between which the stator laminations of sheet steel are securely clamped and riveted under hydraulic pressure. This construction exposes the laminations directly to the air and improves the radiation, thus insuring high overload capacity and low operating temperatures. The field slots are overhung or partially closed, affording mechanical protection to the coils.

Ques. Why are induction motors called "asynchronous"?

Ans. Because the armature does not turn in synchronism with the rotating field, or, in the case of a single phase induction motor, with the oscillating field (considering the latter in the light of a rotating field).

Ques. How does the speed vary?

Ans. It is slower (more or less according to load) than the *"field speed," that* is, than "synchronism" or the "synchronous *speed."*



FIGS. 1,644 to 1,649.—Construction of General Electric drawn shell fractional horse power motors. The distinguishing feature of drawn shell motors is the field construction which consists of a steel shell or cylinder supporting and clamping together the stator or field punchings. This method avoids the cast frame work outside the active magnetic material. A disc is first punched or "blanked" out of soft steel, fig. 1,644, this disc being faced into the shape, fig. 1,645, with one end closed. The other end of the shell is then cut out, leaving the small flange as in fig. 1646. It is now ready to receive the core punchings. In the next operation a suitable number of spacing rings, fig. 1,647, are forced into the shell and seated against the retaining lip, which may be seen in fig. 1,646. The field punchings or laminae, fig. 1,648, are now assembled, after which a second and equal set of spacing rings are put into place to center the active field iron. The open edge of the shell is then rolled over the punchings under heavy pressure, thus preparing the field structure for the machinings and fitting of the end heads and base. Fig. 1,649 shows a section of the completely assembled field structure, the parts being cut away to indicate the relation between the field punchings, spacing rings and shell. After the spacing rings at both frame ends have been turned true and grooved, the bearing heads, fig. 1,649, are ready for fastening in place by four fillister headed screws. A complete wound field is shown in fig. 1,858, with flat base casting attached.

Ques. What is the difference of speed called?

Ans. The *slip*.

This is a vital factor in the operation of an induction motor, since *there must be slip in order that the armature inductors shall cut magnetic lines* to **induce** (hence the name "**induction**" motor) currents therein so as to create a driving torque.

FIG. 1,650.—Ideal fifteen horse power two phase induction motor. The armature core is supported by a cast iron frame carried on a base, with sliding ways and screw adjustment for tightening the belt. The armature core is provided with ventilating apertures, with metal spacers between each tooth. The revolving field is a steel casting with radially projecting poles, to which the pole shoes are bolted. The overhanging pole tips retain the field coils. All coils of the smaller sizes are wound with insulated copper wire of square section, and of the larger sizes, with flat copper, wound on edge, each turn being insulated by sheet insulation. Motors of this type are adapted for use in small power plants and isolated plants. The relatively high speed for which they are designed, reduces considerably the weight and overall dimensions, and likewise the cost. The exciter is belt driven. The normal kw. capacity of the exciter usually exceeds the kw. required for the excitation under normal load conditions to permit of station lighting. All exciters are built as compound wound dynamos, capable of delivering the exciter current up to 125 volts, which is sufficient margin in the field to control the alternating current line voltage on circuits of unusually low power factor.

Ques. What is the extent of the slip?

Ans. It varies from about 2 to 5 per cent. of synchronous speed depending upon the size.

Ques. Why are induction motors sometimes called constant speed motors?

Ans. They are erroneously and ill advisedly, yet convenientl *so called by* builders to distinguish them from induction mot

fitted with special devices to obtain widely varying speeds, and which are known as *variable speed* induction motors.

The term *adjustable* would be better.

Motor, Constant Speed.—A motor in which the speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct current shunt motors.—Paragraph 46 of 1907 Standardisation Rules of the A.I.E.E.

Motor, Variable Speed.—A motor in which provision is made for varying the speed as desired. The A.I.E.E. has unfortunately introduced the term *varying speed motor*, to designate "motors in which the speed varies with the load, decreasing when the load increases, such as series motors." The term is objectionable, since by the expression *variable speed motor* a much more general meaning is intended.

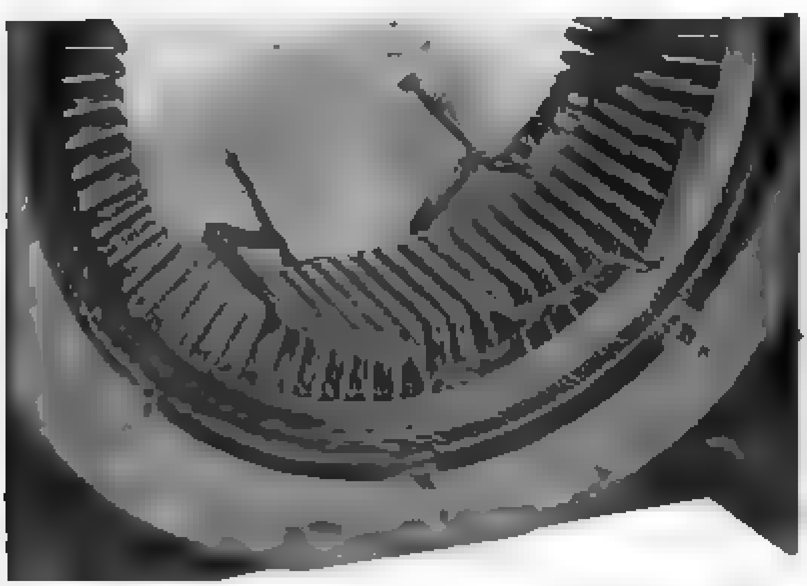


FIG. 1,651.—Western Electric core construction and method of winding field of skeleton frame induction motor. The coils are wound on forms to give them exact shape and dimensions required They are pressed into hot moulds to remove any irregularities and then the coils are impregnated with hot cement, to bind the layers together in their permanent shape. The portion of the coil which fits into the slot is wrapped with varnished cloth and a layer of dry tape is wound over the entire coil The coils are then impregnated with an insulating compound and baked, the process being repeated six times. Coils for 1,100 and 2,200 volt motors have an extra covering of insulation and double the amount of impregnating and baking. The coils may be furnished with special insulation and treatment for exceptionally severe service conditions, such as exposure to excessive moisture, extreme heat, acid or alkaline fumes, etc. The coils are accessible and for the final finish are sprayed with black varnish.

Ques. Why do some writers call the field magnets and armature the *primary* and *secondary*, respectively?

Ans. Because, in one sense, the induction motor is a species *of transformer*, that is, it acts in many respects like a transformer, *the primary* winding of which is on the field and the *secondary winding* on the armature.

In the motor the function of the secondary circuit is to furnish energy to produce a torque, instead of producing light and heat as in the case of the transformer. Such comparisons are ill advised when made for the purpose of supplying names for motor parts. There can be no confusion by employing the simple terms armature and field magnets, remembering that the latter is *that part that produces the oscillating or rotating field* (according as the motor is single or polyphase), and the former, *that part in which currents are induced*.

FIG. 1,652.—Armature of Allis-Chalmers squirrel cage induction motor. The frame casting is of the box type and has large cored openings for ventilation. Lugs are cast on the interior surface of the frame to support the core, leaving a large air space between.

Ques. Why are polyphase induction motors usually presented in text books before single phase motors?

Ans. Because the latter must start with a rotating field and come up to speed before the oscillating field can be employed.

A knowledge then of the production of a rotating field is necessary *to understand* the action of the single phase motor at starting.

Polyphase Induction Motors.—As many central stations put out only alternating current circuits, it has become necessary for motor builders to perfect types of alternating current motor suitable for all classes of industrial drive and which are adapted for use on these commercial circuits. Three phase

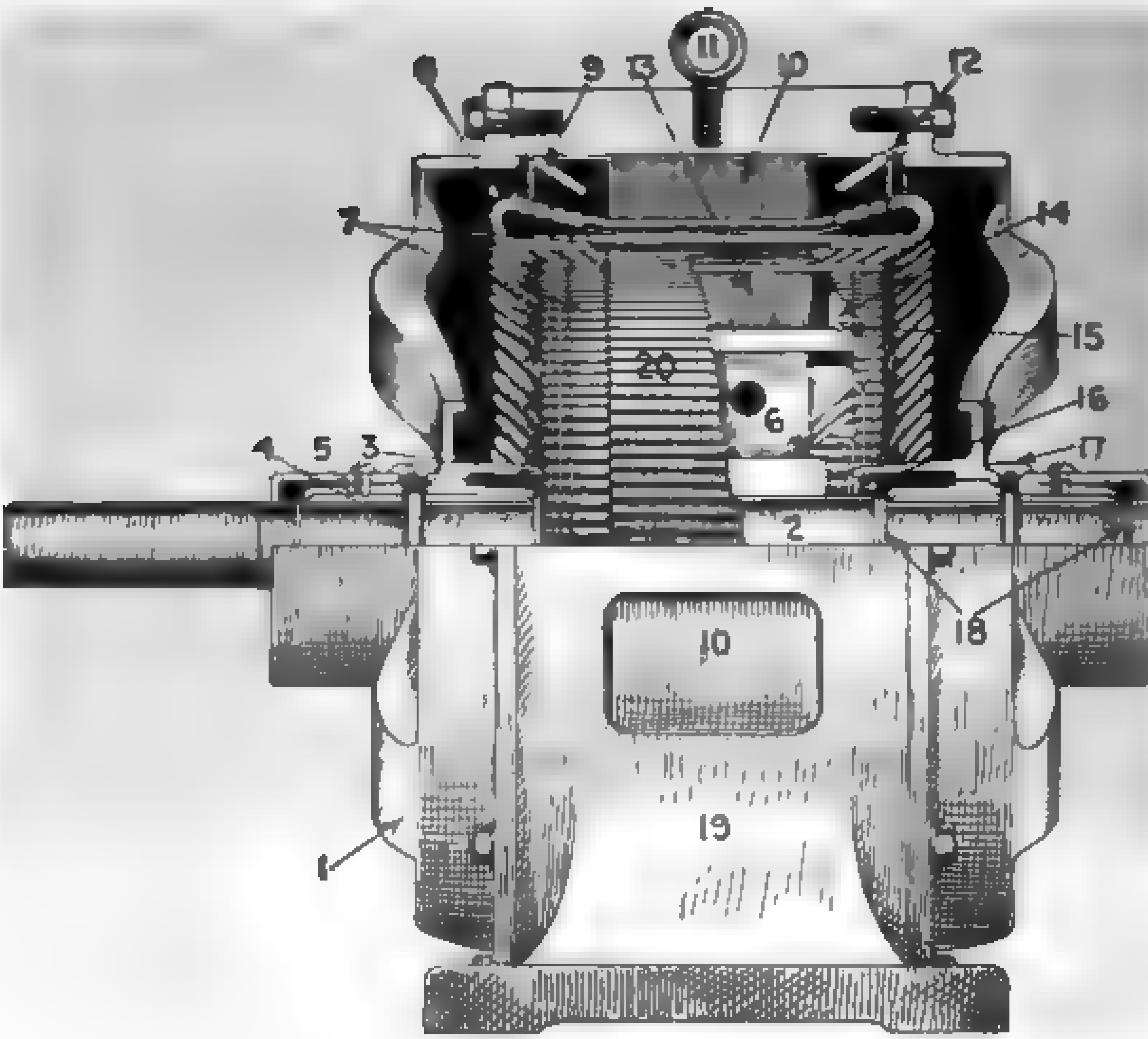


FIG. 1,653.—Sectional view showing parts of Reliance polyphase induction motor. A special feature of the squirrel cage armature construction is the multiplicity of short circuiting rings. The holes in the rings are bored slightly smaller than the diameter of the copper rods, and the force fit gives good contact. The rings having been forced in place are dip soldered in an alloy of tin of high melting point. The motor parts are. 1, end yoke; 2, shaft; 3, armature short circuiting rings; 4, oil ring; 5, self-aligning bearing bushing; 6, spider; 7, armature bars; 8, field coils, 9, field lamination end plate, 10, field laminations; 11, eye bolt; 12, stator locking key; 13, armature laminations, 14, armature lamination end plate; 15, armature locking key; 16, dust cap; 17, oil well cover; 18, oil thrower; 19, field frame; 20, squirrel cage armature.

induction motors are slightly more efficient at all loads than two phase motors of corresponding size, due to the superior distribution of the field windings. The power factor is higher, especially at light loads, and the starting torque with full load current is also greater. Furthermore, for given requirements of load and voltage, the amount of copper required in the distributing system is less; consequently, wherever service conditions will permit, three phase motors are preferable to two phase.

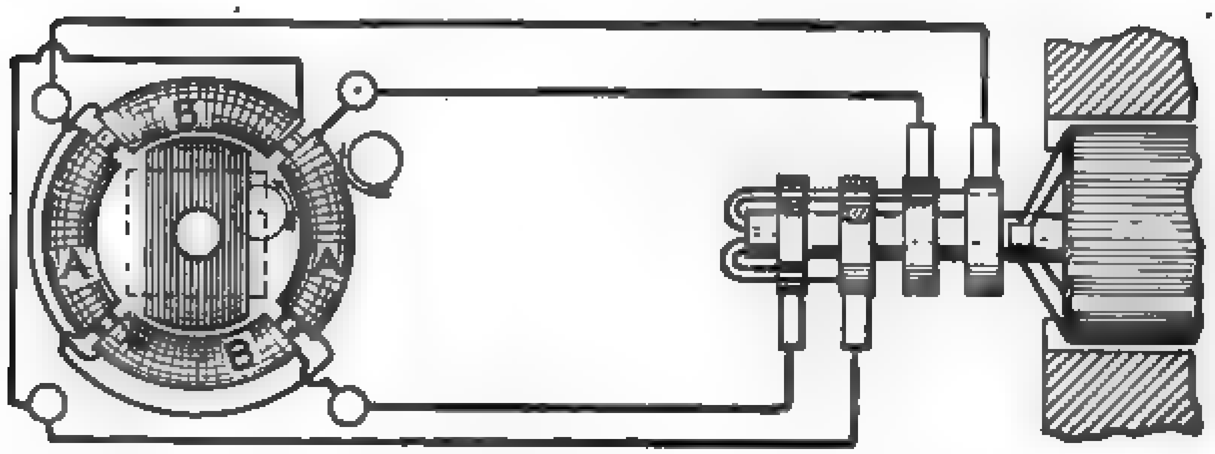


FIG. 1,654.—Tesla's rotating magnetic field. The figure is from one of Tesla's papers as given in The Electrician, illustrating how a rotating magnetic field may be produced with stationary magnets and polyphase currents. The illustration shows a laminated iron ring overwound with four separate coils, AA, and BB, each occupying about 90° of the periphery. The opposite pairs of coils AA and BB respectively are connected in series and joined to the leads from a two phase alternator, the pair of coils AA being on one circuit and the coils BB on the other. The resultant flux may be obtained by combining the two fluxes due to coils AA and BB, taking account of the phase difference of the two phase current, as in fig. 1,655.

The construction of an induction motor is very simple, and since there are no sliding contacts as with commutator motors, there can be no sparks during operation—a feature which adapts the motor for use in places where fire hazards are prominent.

The motor consists, as already mentioned, simply of two parts: *an armature and field magnets*, *without any electrical connection between these parts*. Its operation depends upon:

1. *The production of a rotating field;*
2. *Induction of current in the armature;*
3. *Reaction between the revolving field and the induced currents.*

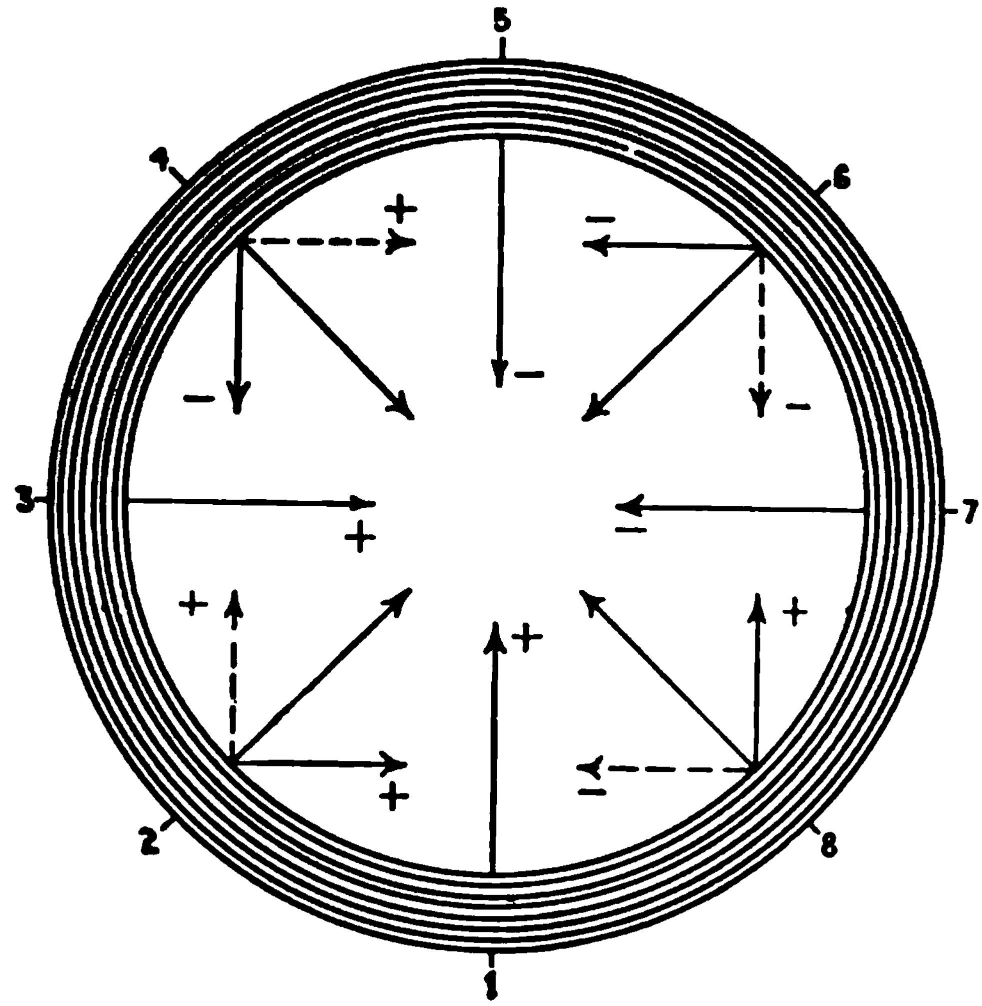


FIG. 1,655.—Method of obtaining resultant flux of Tesla's rotating magnetic field. The eight small diagrams here seen show the two components and resultant for eight equivalent successive instants of time during one cycle. At 1, the vertical flux is at + maximum and the horizontal is zero. At 2, the vertical flux is still + but decreasing, and the horizontal is + and increasing, the resultant is the thick line sloping at 45° upwards to the right; At 3, the vertical flux is zero, and the horizontal is at its + maximum, and similarly for the other diagrams. Thus at 8, the vertical flux is + and increasing, while the horizontal is − and decreasing, the resultant is the thick line sloping at 45° upwards to the left. At points 2, 4, 6, and 8 the increasing fluxes are denoted by full and the decreasing by dotted lines. The laminated iron of the ring is indicated by the circles, and the result is that at the instants chosen the flux across the plane of the ring is directed inwards from the points 1, 2, 3, 4, etc., on the inner periphery of the iron. There will, therefore, appear successively at these points effective north poles, the corresponding south poles being simultaneously developed at the points diametrically opposite. These poles travel continuously from one position to the next, and thus the magnetic flux across the plane of the ring swings round and round, completing a revolution without change of intensity during the cycle time of the current.

Production of a Rotating Field.—It should at once be understood that the term "rotating field" does not signify that part of the apparatus revolves, the expression merely refers to

the magnetic lines of force set up by the field magnets without regard to whether the latter be the stationary or rotating member.

A rotating field then may be defined as *the resultant magnetic field produced by a system of coils symmetrically placed and supplied with polyphase currents.*

A rotating magnetic field can, of course, be produced by spinning a horse shoe magnet around its longitudinal axis, but with polyphase currents, as will be later shown, the rotation of the field can be produced without any movement of the mechanical parts of the electro magnets.

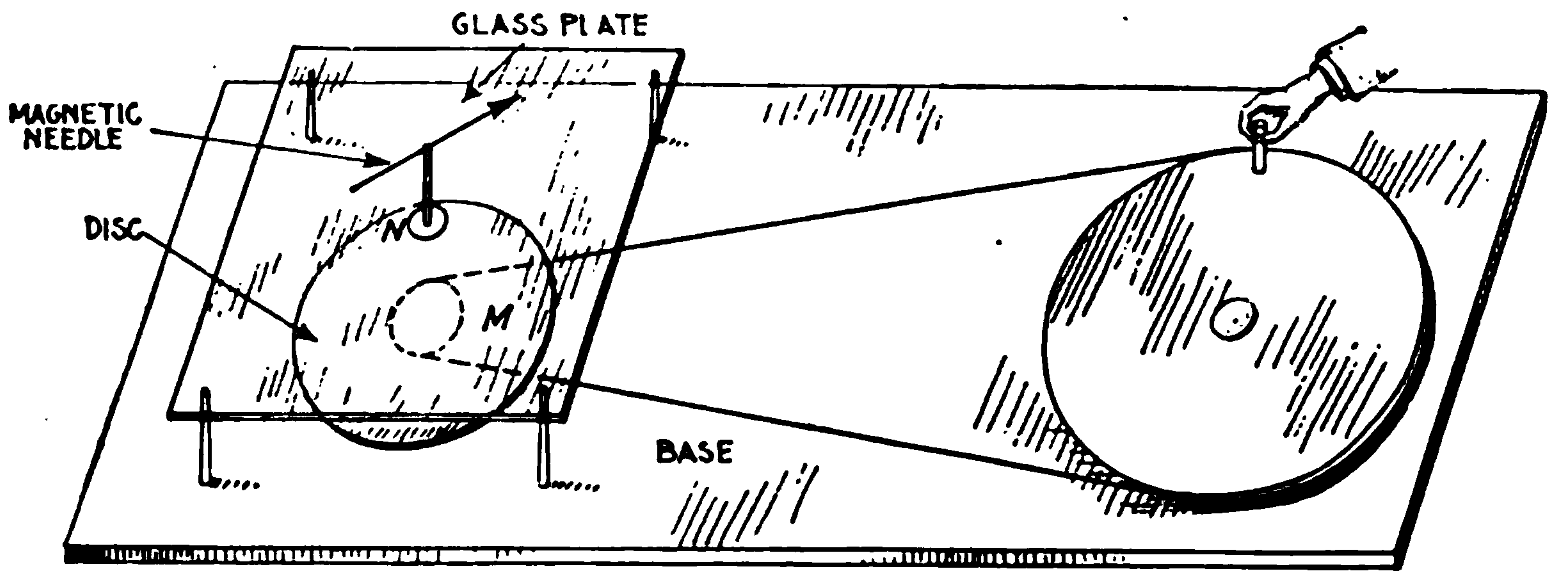


FIG. 1,656.—Arago's rotations. The apparatus necessary to make the experiment consists of a copper disc M, arranged to rotate around a vertical axis and operated by belt drive, as shown. By turning the large pulley by hand, the disc M may be rotated with great rapidity. Above the disc is a glass plate on which is a small pivot supporting a magnetic needle N. If the disc now be rotated with a slow and uniform velocity, the needle is deflected in the direction of the motion, and stops at an angle of from 20° to 30° with the direction of the magnetic meridian, according to the velocity of the rotation of the disc. If the velocity increase, the needle is ultimately deflected more than 90° and then continues to follow the motion of the disc.

The original rotating magnetic field dates back to 1823, when Francois Jean Arago, an assistant in Davy's laboratory, discovered that if a magnet be rotated before a metal disc, the latter had a tendency to follow the motion of the magnet, as shown in fig. 290, page 270 and also in fig. 1,656. This experiment led up to the discovery which was made by Arago in 182 when he observed that the *number* of oscillations which a magnet

[redacted]

needle makes in a given time, under the influence of the earth's magnetism, is very much lessened by the proximity of certain metallic masses, and especially of copper, which may reduce the number in a given time from 300 to 4.

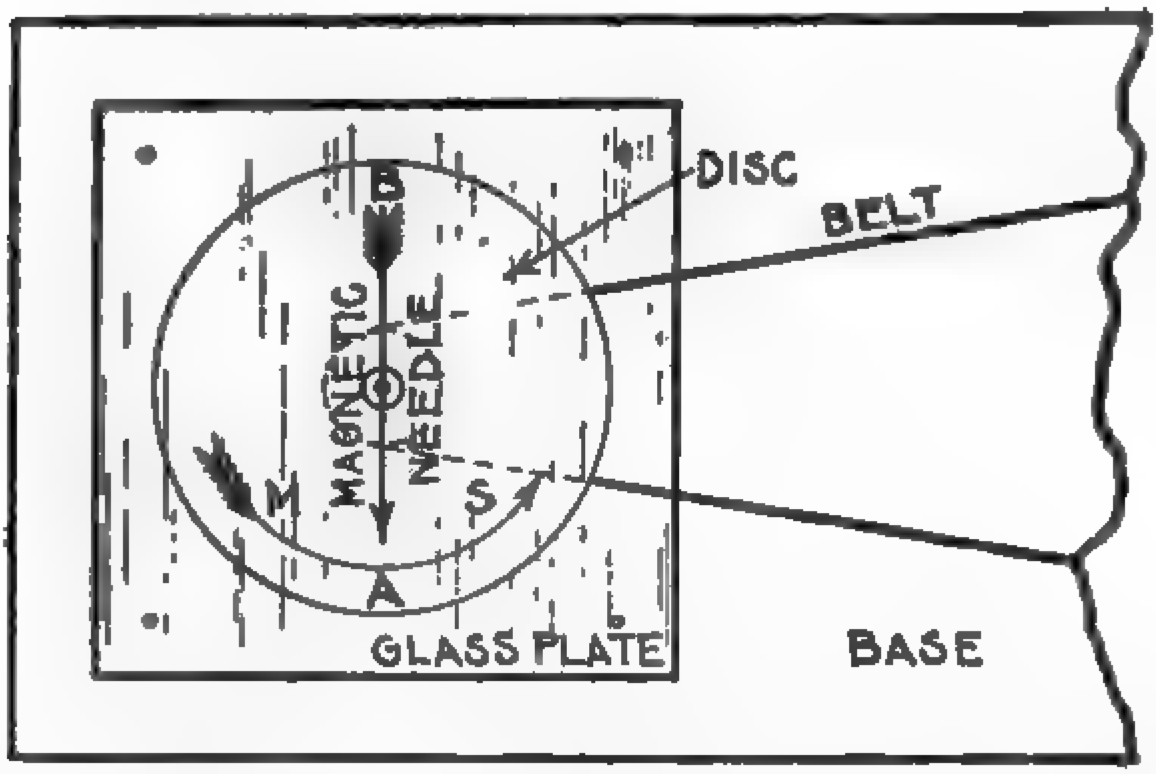


FIG. 1,657.—Explanation of Arago's rotations. Part of fig. 1,656 is here reproduced in plan. Faraday was the first to give an explanation of the phenomena of magnetism by rotation in attributing it to the induction of currents which by their electro-dynamic action, oppose the motion producing them; the action is mechanically analogous to friction. In the figure, let AB be a needle oscillating over a copper disc, and suppose that in one of its oscillations it goes in the direction of the arrow from M to S. In approaching the point S, for instance, it develops there a current in the opposite direction, and which therefore repels it; in moving away from M it produces currents which are of the same kind, and which therefore attract, and both these actions concur in bringing it to rest. Again, suppose the metallic mass turn from M towards S, and that the magnet be fixed; the magnet will repel by induction points such as M which are approaching A, and will attract S which is moving away; hence the motion of the metal stops, as in Faraday's experiment. If in Arago's experiment the disc be moving from M to S, M approaches A and repels it, while S, moving away, attracts it; hence the needle moves in the same direction as the disc. If this explanation be true, all circumstances which favor induction will increase the dynamic action; and those which diminish the former will also lessen the latter.

The explanation of Arago's rotations is that ***the magnetic field cutting the disc produces eddy currents therein and the reaction between the latter and the field causes the disc to follow the rotations of the field.***

The induction motor is a logical development of the experiment of Arago, which so interested Faraday while an assistant in Davy's laboratory and which led him to the discovery of the laws of electro-magnetic induction, which are given in Chapter X.

*In 1885, Professor **Ferraris**, of Turin **discovered** that *a rotating field could be produced from stationary coils by means of polyphase currents.*

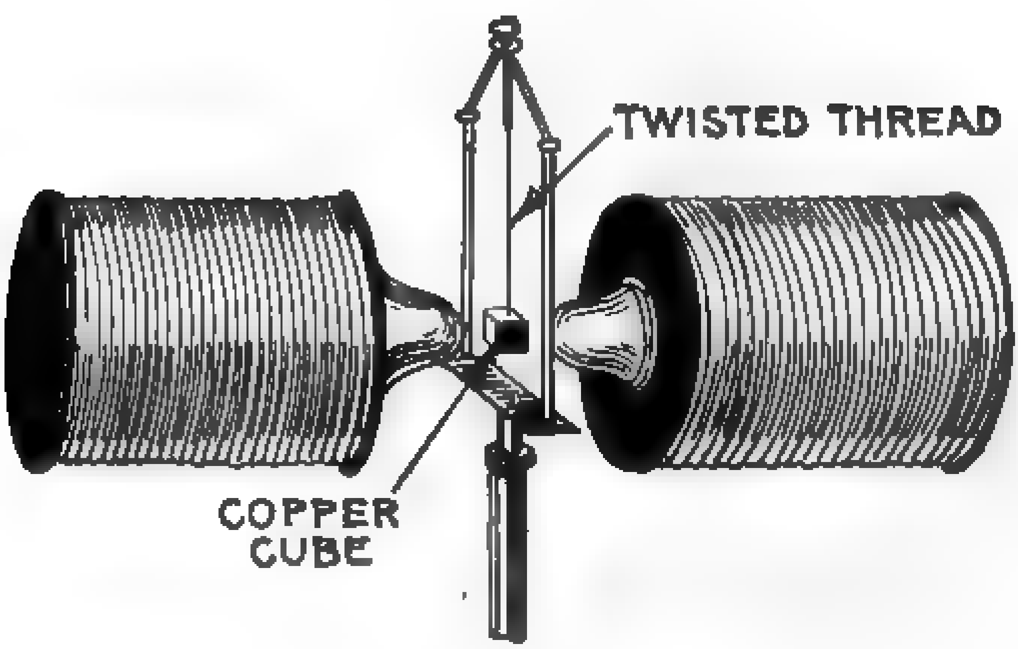


FIG. 1,658.—Experiment made by Faraday being the reverse of Arago's first observation. Faraday assumed that since the presence of a metal at rest stops the oscillations of a magnetic needle, the neighborhood of a magnet at rest ought to stop the motion of a rotating mass of metal. He suspended a cube of copper by a twisted thread, which was placed between the poles of a powerful electromagnet. When the thread was left to itself, it began to spin round with great velocity, but stopped the moment a powerful current was passed through the electro-magnet.

†This discovery was commercially applied a few years later by Tesla, Brown, and Dobrowolsky.

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*NOTE.—Walmsley attributes the first production of rotating fields to Walter Bailey in 1879, who exhibited a model at a meeting of the Physical Society of London, but very little was done, it is stated, until Ferraris took up the subject.

†*NOTE.—The Tesla patents were acquired in the U. S. by the Westinghouse Co. in 1888 and polyphase induction motors*, as they were called, were soon on the market. Brown of the *Oerlikon Machine Works* developed the single phase system and operated a transmission *plant over five miles in length* at Kassel, Germany, which operated at 2,000 volts.

The principles of polyphase motors **can be best understood by means of elementary diagrams illustrating the action of polyphase currents in producing a rotating magnetic field, as explained in the paragraphs following.**

Production of a Rotating Magnetic Field by Two Phase Currents.—Fig. 1,659 represents an iron ring wound with coils of insulated wire, which are supplied with a two phase current at the four points A, B, C, D, the points A and B, and C and D, being electrically connected.

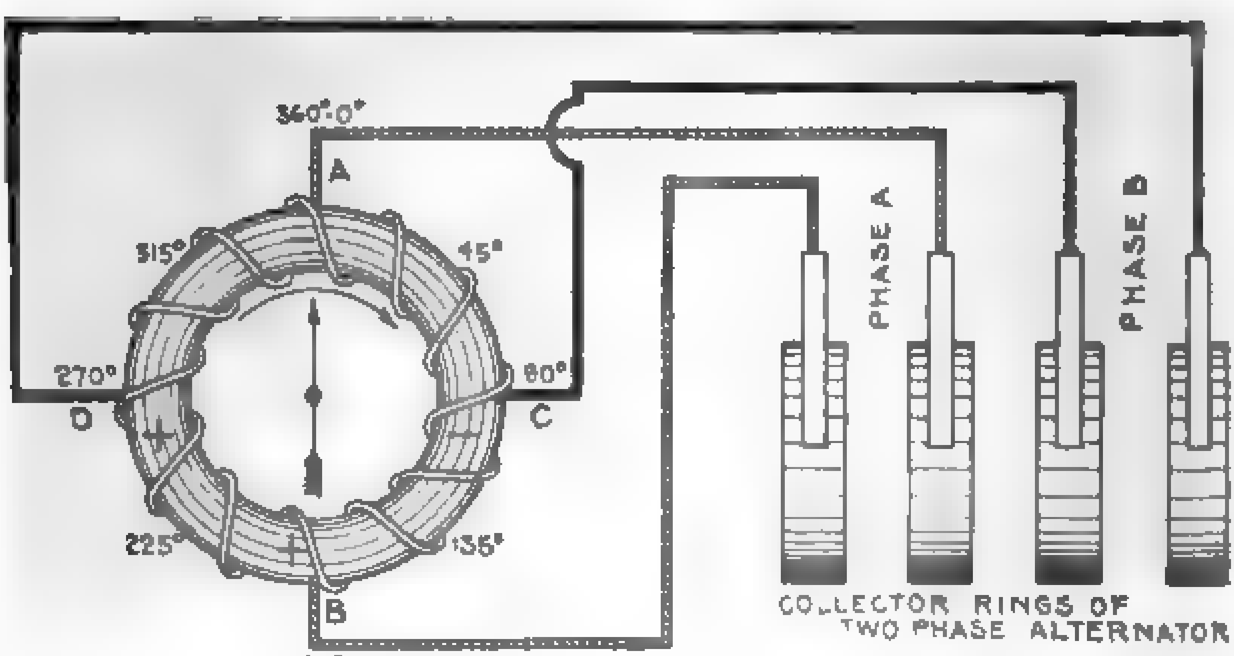


FIG. 1,659.—Production of a rotating magnetic field by two phase currents. The figure represents an iron ring, wound with coils of insulated wire, and supplied with two phase currents at the four points A, B, C and D. The action of the two phase current on the ring in producing a rotating magnetic field is explained in the accompanying text.

According to the principles of electro-magnetic induction, if only one current *a* entered the ring at A, and the direction of the winding be suitable, a negative pole (—) will be produced at A and a positive pole (+) at B, so that a magnetic needle *pivoted in the* center of the ring would tend to point vertically

upward towards A. Now suppose that at this instant, corresponding to the beginning of an alternating current cycle, a second current *b*, differing in phase from the first by 90 degrees, is allowed to enter the ring at C. As shown in fig. 1,659, when the pressure of the current *a* is at its maximum, that of the current *b* is at its minimum; therefore, even a two phase current, at the beginning of the cycle, the needle will point toward A.

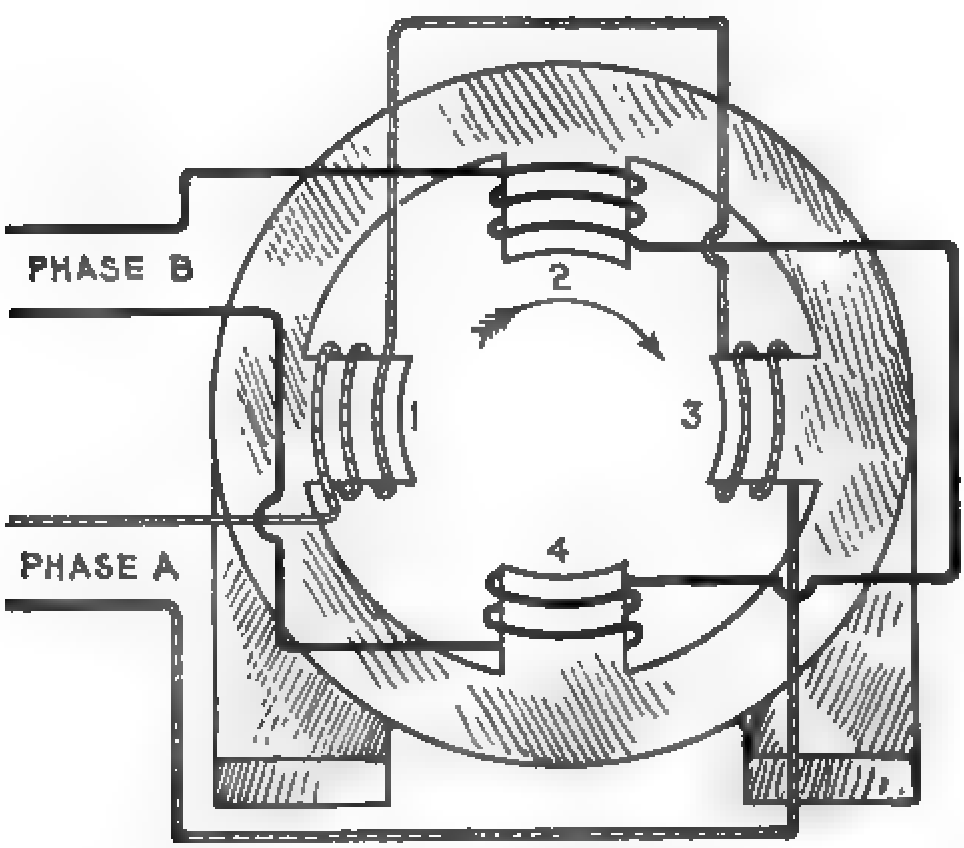


FIG. 1,660.—Production of rotating magnetic field in a two pole two phase motor. The poles are numbered from 1 to 4 in a clockwise direction. Phase A winding is around poles 1 and 3, and phase B winding, around poles 2 and 4. In each case the poles are wound alternately, that is, if 1 be wound clockwise, 3 will be wound counter clockwise, thus producing unlike polarity in opposite poles. Now during one cycle of the two phase current, the following changes take place, starting with pole 1 of N polarity and 3, of S polarity:

	One Cycle			
Degrees	0° to 90°	90° to 180°	180° to 270°	270° to 360°
Polarity	1N – 3S	2N – 4S	3N – 1S	4N – 2S

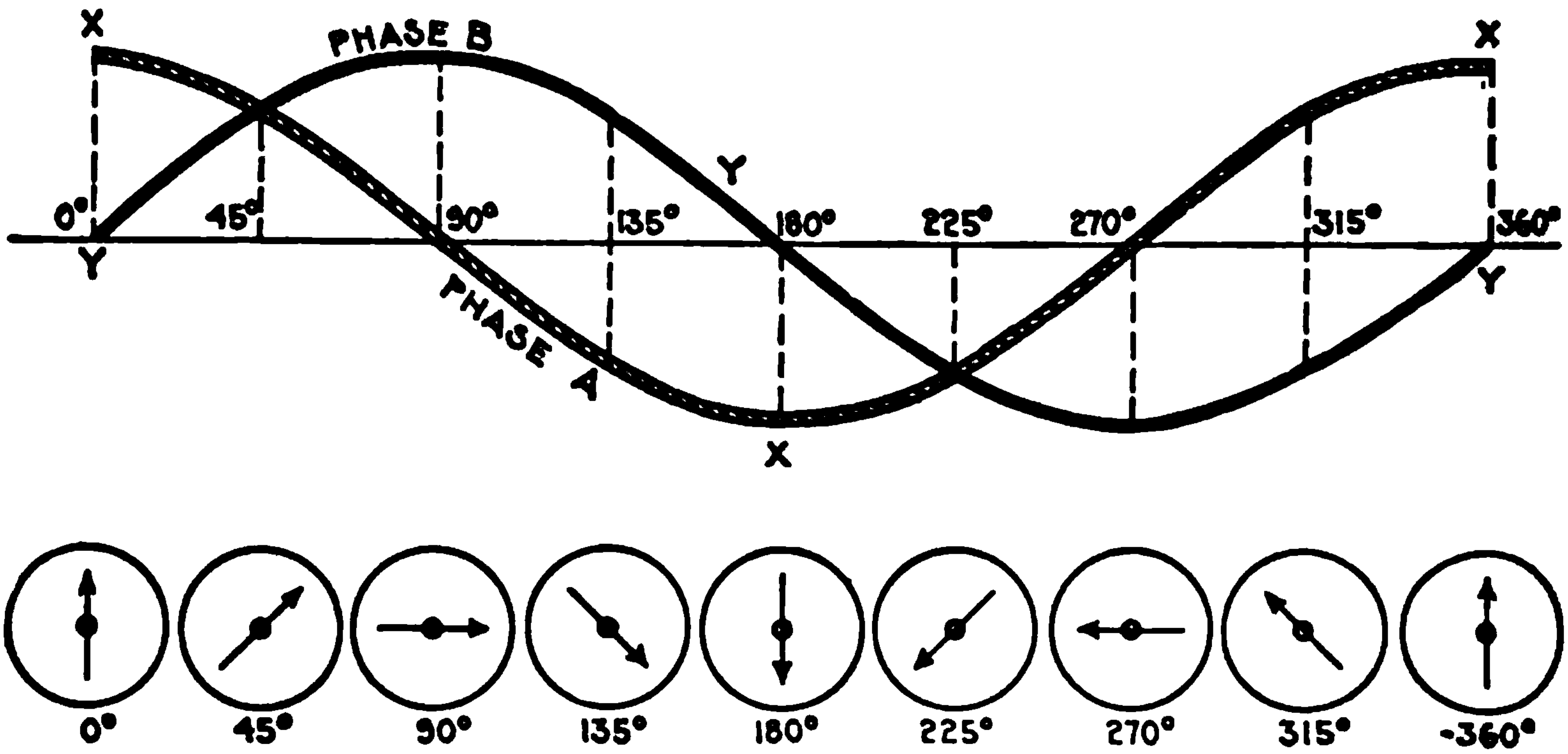


FIG. 1,661.—Diagram showing resultant poles due to two phase current.

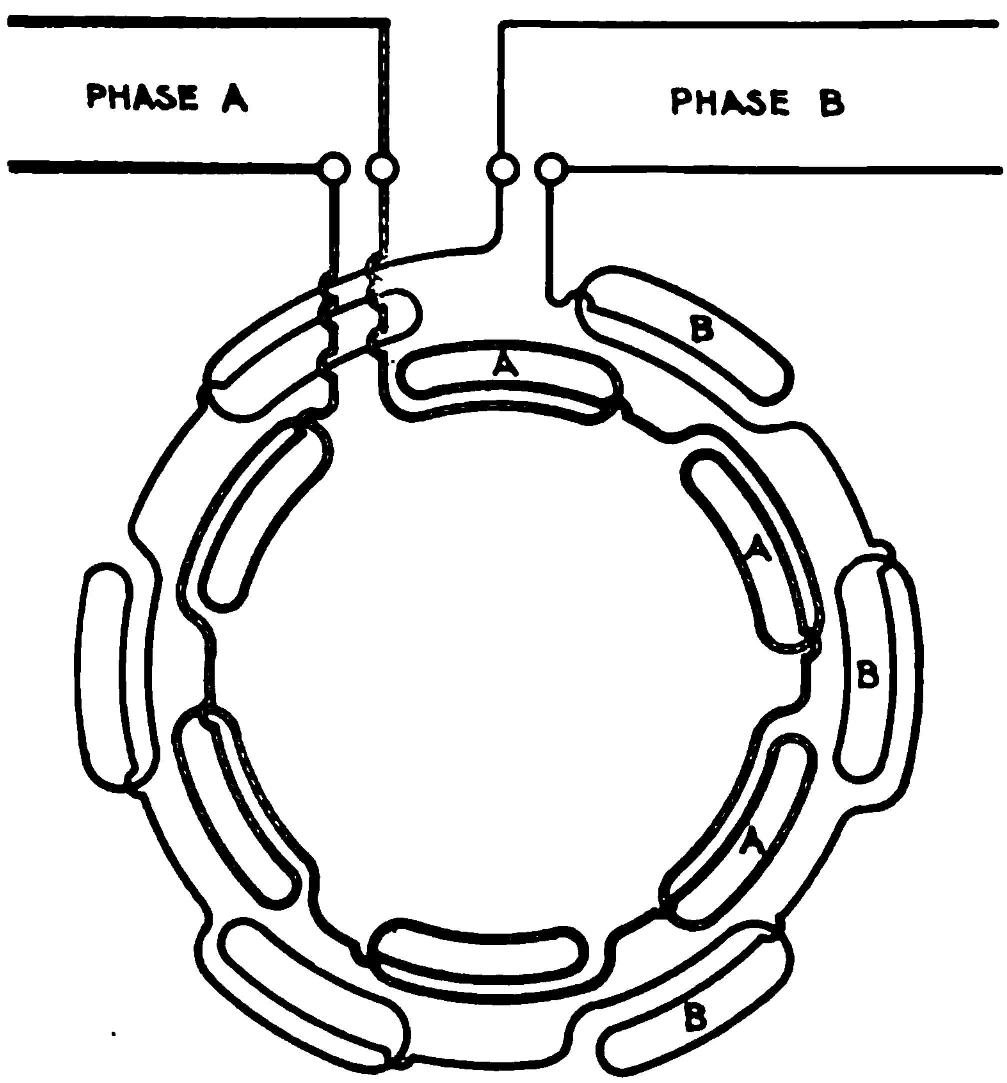


FIG. 1,662.—Diagram of two phase, six pole field winding. There are six coils in each phase, as shown. The coils of each phase are connected in series, adjacent coils being joined in opposite senses, thus, for each phase, first one coil is wound clockwise, and the next counter clockwise.

As the cycle continues, however, the strength of *a* will diminish and that of *b* increase, thus shifting the induced pole toward C, until *b* attains its maximum and *a* falls to its minimum at 90° or the end of the first quarter of the cycle, when the needle will point toward C. At 90°, the phase *a* current reverses in direction

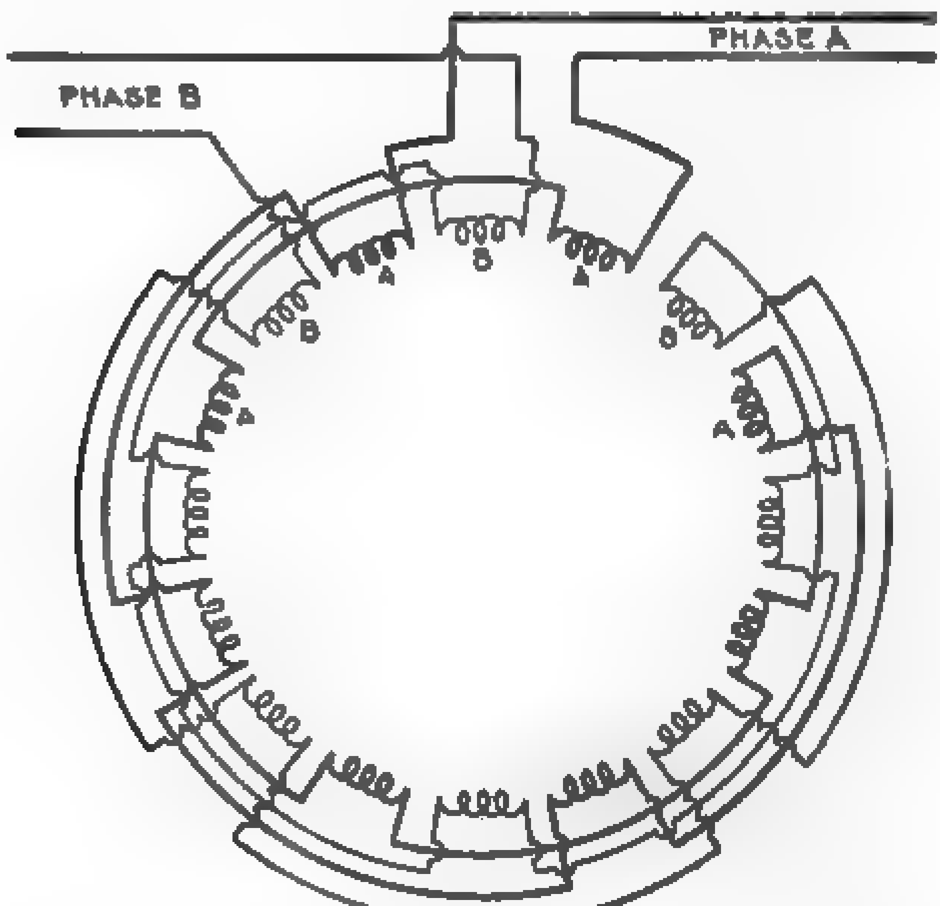
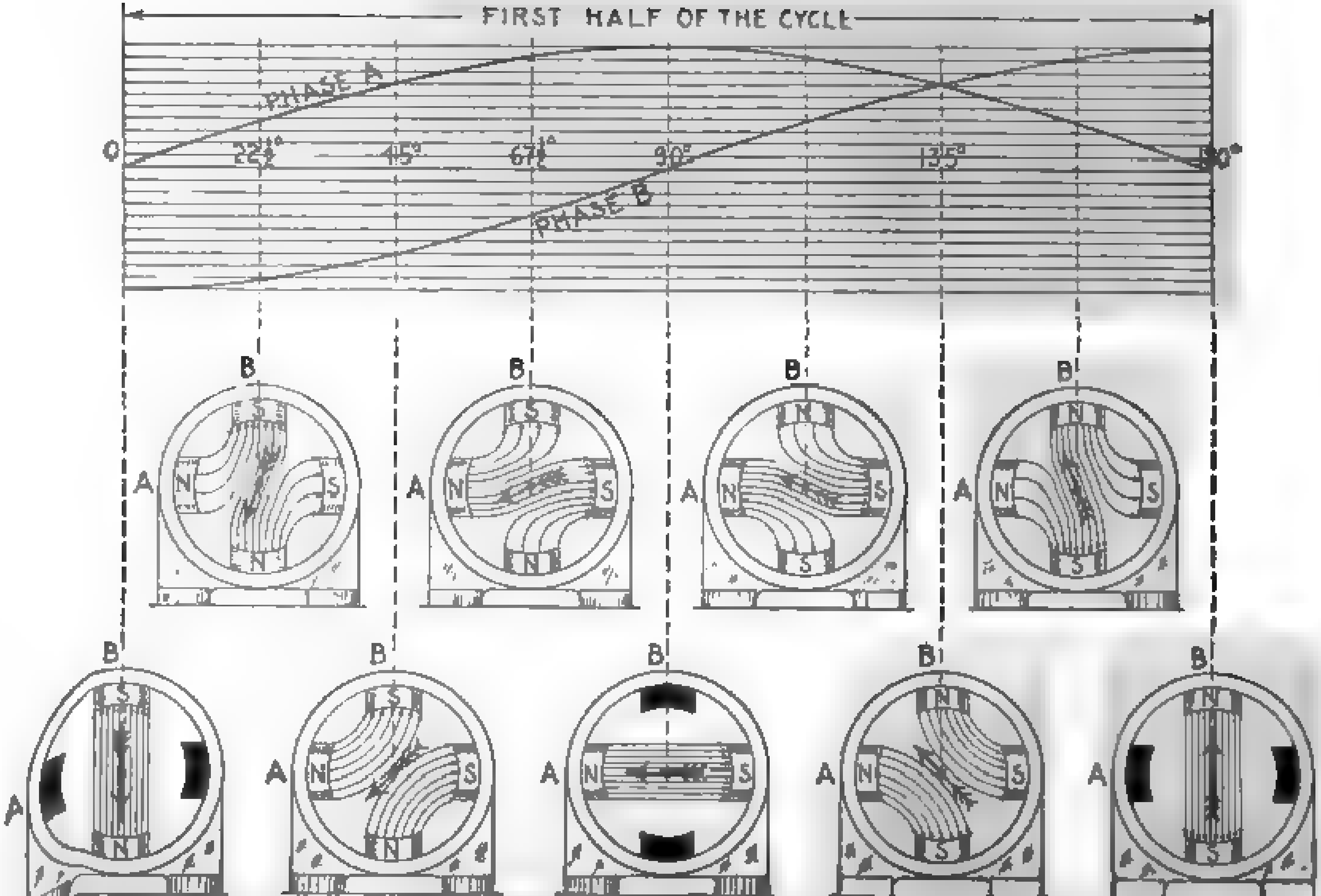
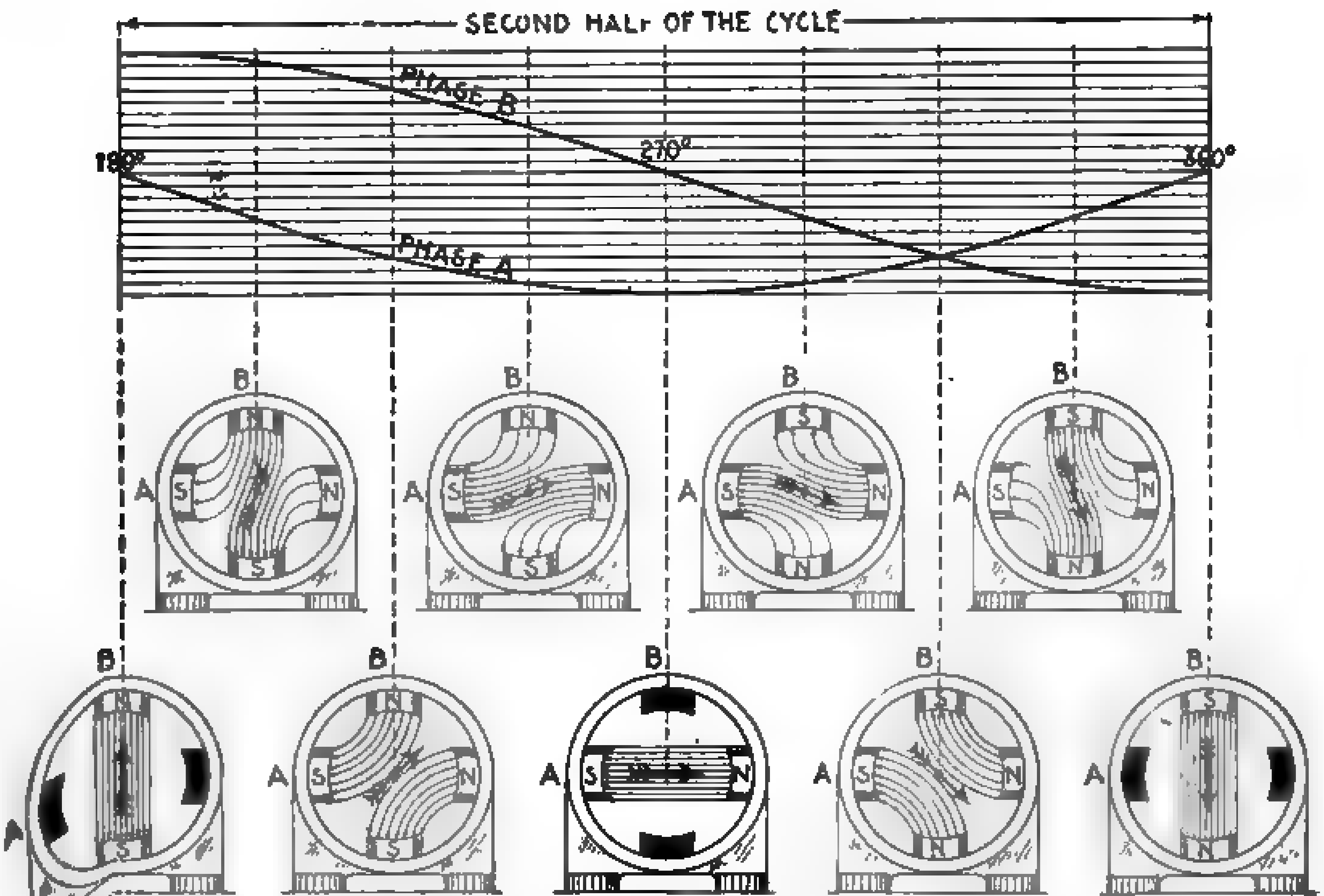


FIG. 1,663.—Diagram of two phase, eight pole field winding. The winding is divided into 16 groups (equal to the product of the number of poles multiplied by the number of phases). Each group such as at A comprises a number of coils in series, each coil being located in a separate pair of slots, the end of one being connected to the beginning of the next. When the currents are in the same direction, the currents circulate in the same direction in two adjacent groups, a pole then with this arrangement being formed by two groups, both phases contributing to the formation of the pole. After ¼ cycle when the current in each phase reverses, the pole advances the angular distance, covered by two groups; hence the field completes one revolution in eight alternations of current.

and produces a negative pole at B, and as its strength increases *from 90° to the 180°* point of the cycle, and that of phase *diminishes,* the resultant negative pole is shifted past C tow



FIGS. 1,664 to 1,683.—Sine curves of two phase current and diagrams showing the physical conception of **a two phase rotating magnetic field.** The alternating magnetizing current is assumed to be of such strength that, at its maximum strength, the field produced may be represented by 10 lines of force as indicated by the parallel lines. At the beginning of the rotation, fig. 1,664, phase A magnetization, according to sine curve is zero, indicated by the solid black poles, while phase B is of strength 10 with



the direction to produce a south pole at B. Similarly, in fig. 1,665, the strength of A is 4 lines, and of B, 9 lines, the magnetization having rotated 22½°. The direction of the resultant magnetization is indicated by the arrow in each It should be noted in fig. 1,669, that the polarity of B is reversed, the current curve now being above the zero line. By the arrow through the successive positions the rotation of the resultant magnetization is clearly seen.

B, until *a* attains its maximum and *b* falls to its minimum at 180°, and the needle points in the direction of B.

At the 180° point of the cycle, *b* reverses in direction and produces a negative pole at D, and as the fluctuation of the pressure of the two currents during the second half of the cycle, from 180° to 360°, bear the same relation to each other as during the first half, the resultant poles of the rotating magnetic field thus produced carry the needle around in continuous rotation so long as the two phase current traverses the windings of the ring.

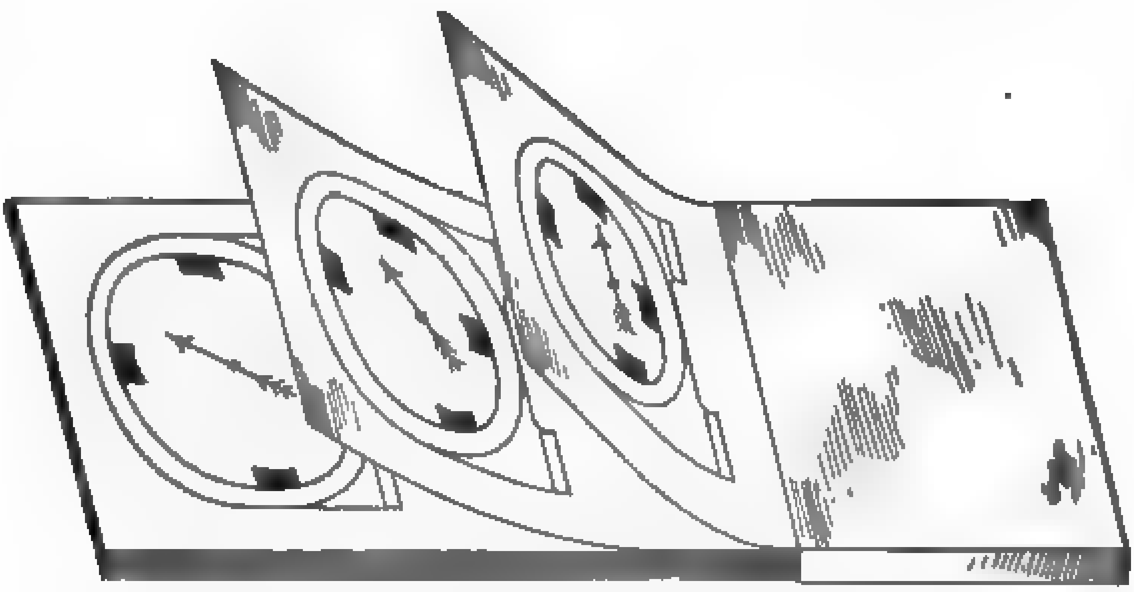


FIG. 1,684.—Moving picture method of showing motion of a rotary magnetic field. A number of sheets of paper are prepared, each containing a drawing of the motor frame and a magnetic needle in successively advancing angular positions, indicating resultant directions of the magnetism. The sheets are bound together so that the axis of the needle on each sheet coincides. When passing the sheets in one way the revolving field will be seen to rotate in one direction, while, when moving the sheets backward, the rotation of the magnetic field is in the opposite direction, showing that the reversal of the order of the coils has the effect of reversing the rotation of the magnetic field.

Production of Rotating Magnetic Field by Three Phase Current.—A rotating magnetic field is produced by the action of a three phase current in a manner quite similar to the action of a two phase current. Fig. 1,685 shows a ring suitably wound *and supplied with* a three phase current at three points A, B, C, *120° of a cycle apart.*

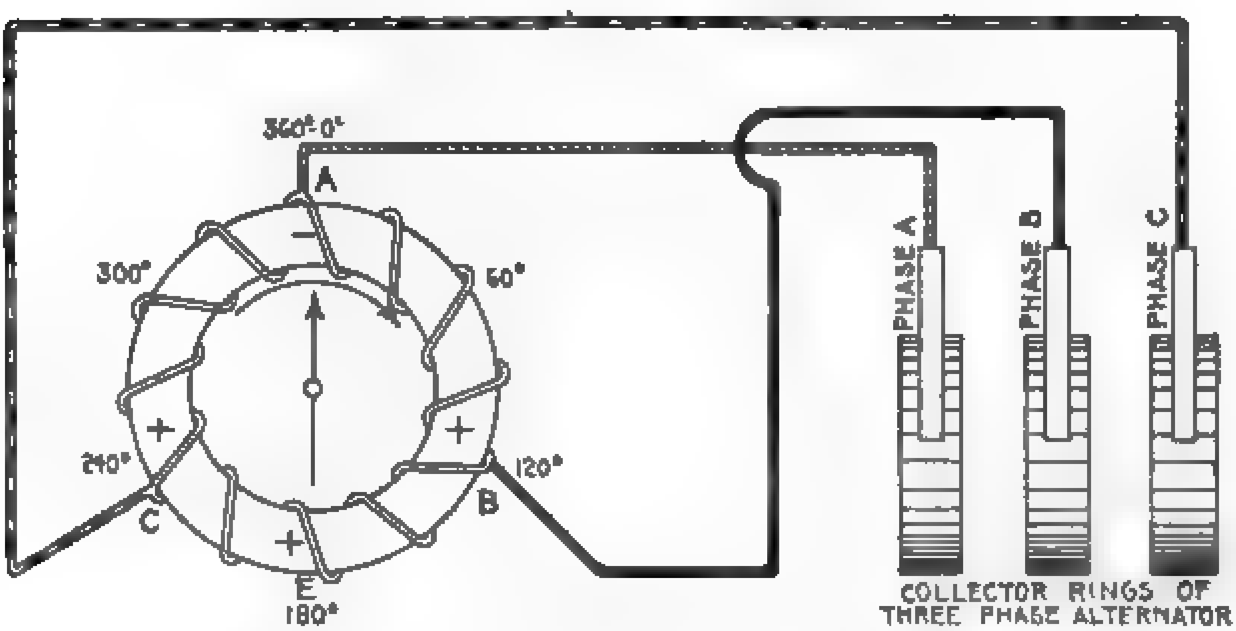


FIG. 1,685.—Production of a rotating magnetic field by three phase current. A ring wound as shown is tapped at points A, B, and C, 120° apart, and connected with leads to a three phase alternator. As described on page 1,304, a rotating magnetic field is produced in a manner similar to the two phase method.

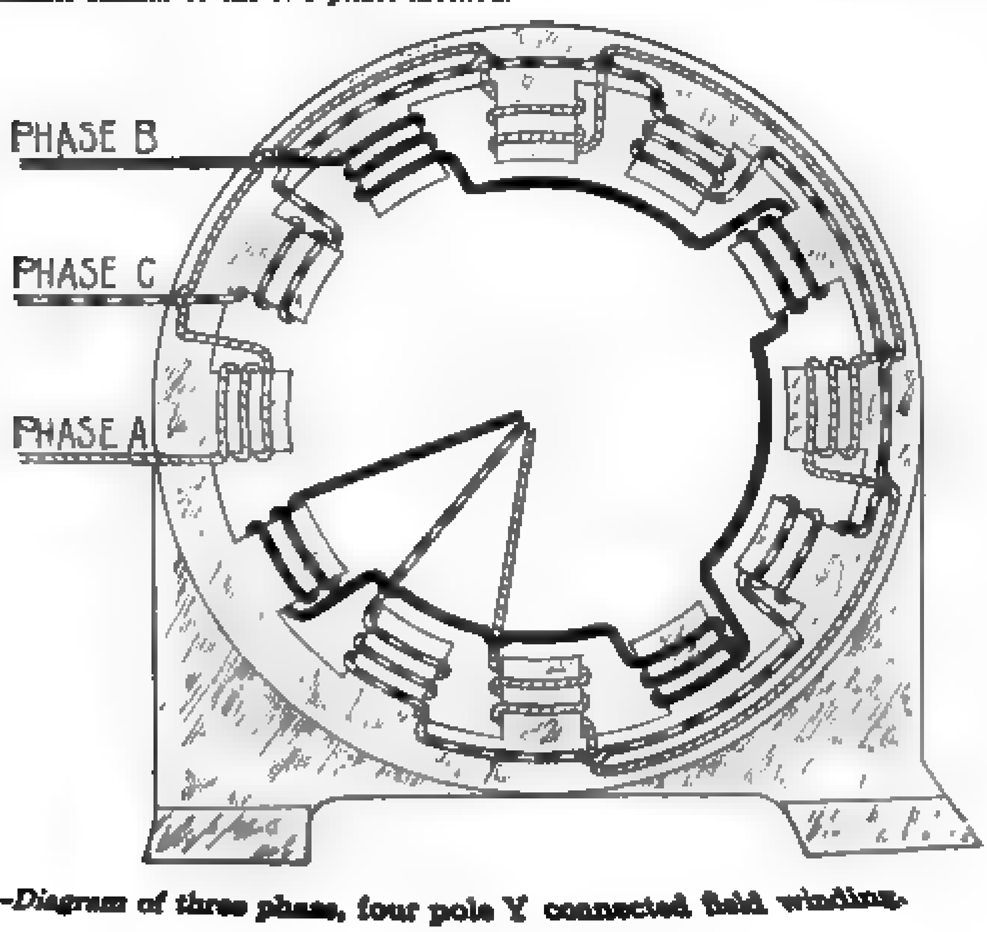


FIG. 1,686.—Diagram of three phase, four pole Y connected field winding.

At the instant when the current *a*, flowing in at A, is at its maximum, two currents *b* and *c*, each one-half the value of *a*, will flow out B and C, thus producing a negative pole at A and a positive pole at B and at C. The resultant of the latter will be a positive pole at E, and consequently, the magnetic needle will point towards A.

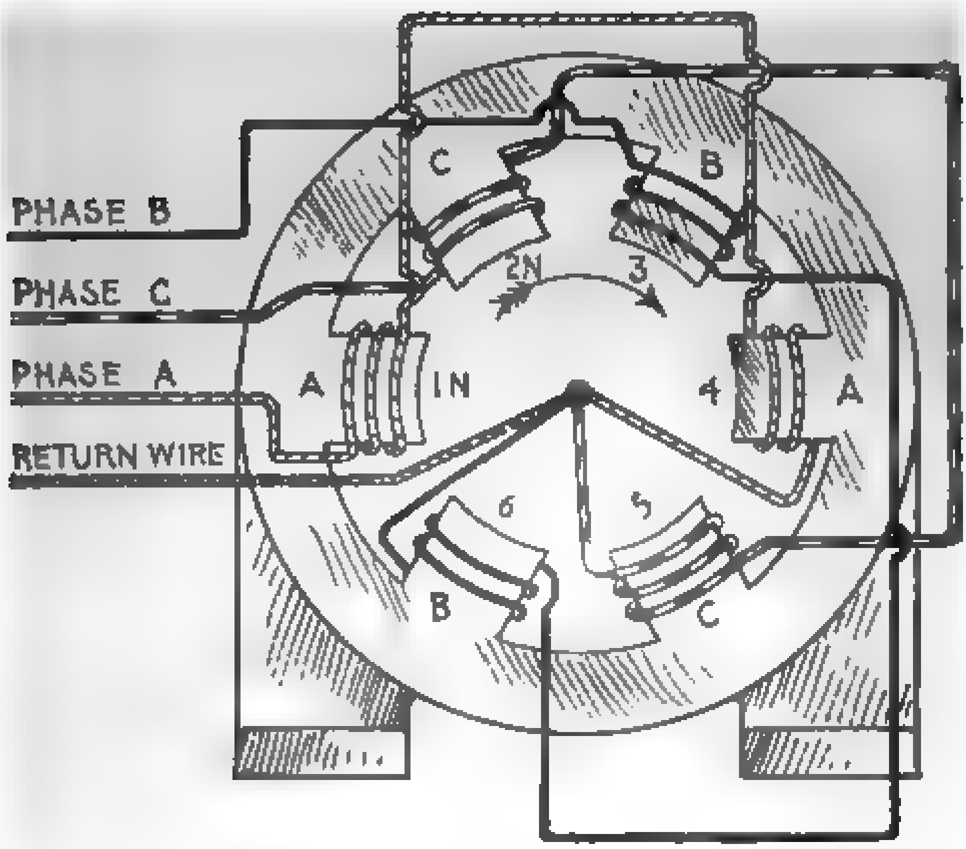


FIG. 1,687.—Production of a rotating magnetic field in a two pole three phase motor. In order to obtain a uniformly rotating magnetic field, it is necessary to arrange the phase windings in the direction of rotation, in the sequence ACB, not ABC as indicated on the magnets. Thus poles 1 and 4 are connected in series to phase A, 2 and 5 in series to phase C, and 3 and 6 in series to phase B. The different phase windings are differently lined, and it should be noted that they have a common return wire, though this is not absolutely necessary. Since the phases of the three currents differ from each other by one-third of a period or cycle, each of the phase windings will therefore set up a field between its poles, which at any instant will differ, both in direction and magnitude, from the fields set up by the other phase windings. Hence, the three phase windings acting together will produce a resultant field, and if plotted out, the directions of this field for various fractions of the period is such that in one complete period the resultant field will make one complete round of the poles in a clockwise direction, as indicated by the curved arrow. The positions of the resultant field during one complete period may be tabulated as follows:

	One Cycle					
	0° to 60°	60° to 120°	120° to 180°	180° to 240°	240° to 300°	300° to 360°
Polarity	1N – 4S	2N – 5S	3N – 6S	4N – 1S	5N – 2S	6N – 3S

As the cycle advances, however, the mutual relations of the fluctuations of the pressures of the three currents, and the time of their reversals of direction will be such, that when a maximum current is flowing at any one of the points A, B, and C, two currents each of one-half the value of the entering current will flow out of the other two points, and when two currents are entering at any two points, a current of maximum value will flow out of the other point. This action will produce one complete rotation of the magnetic field during each cycle of the current.

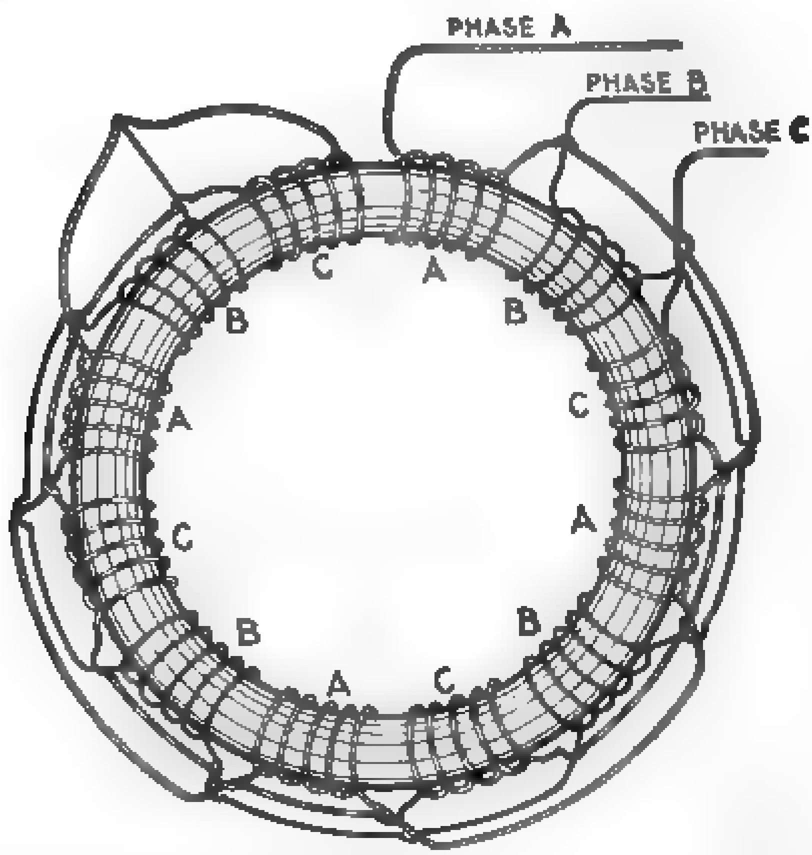
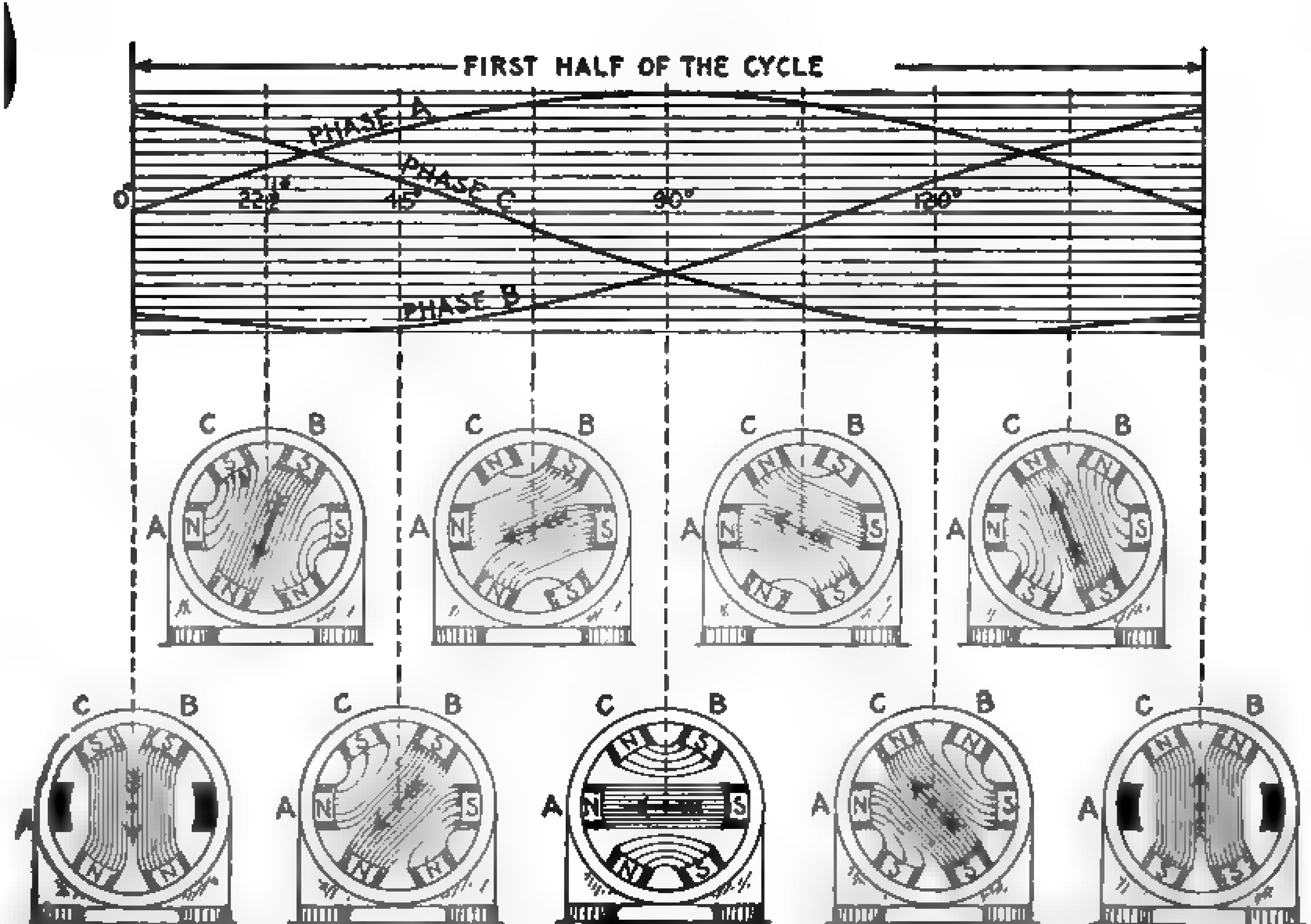
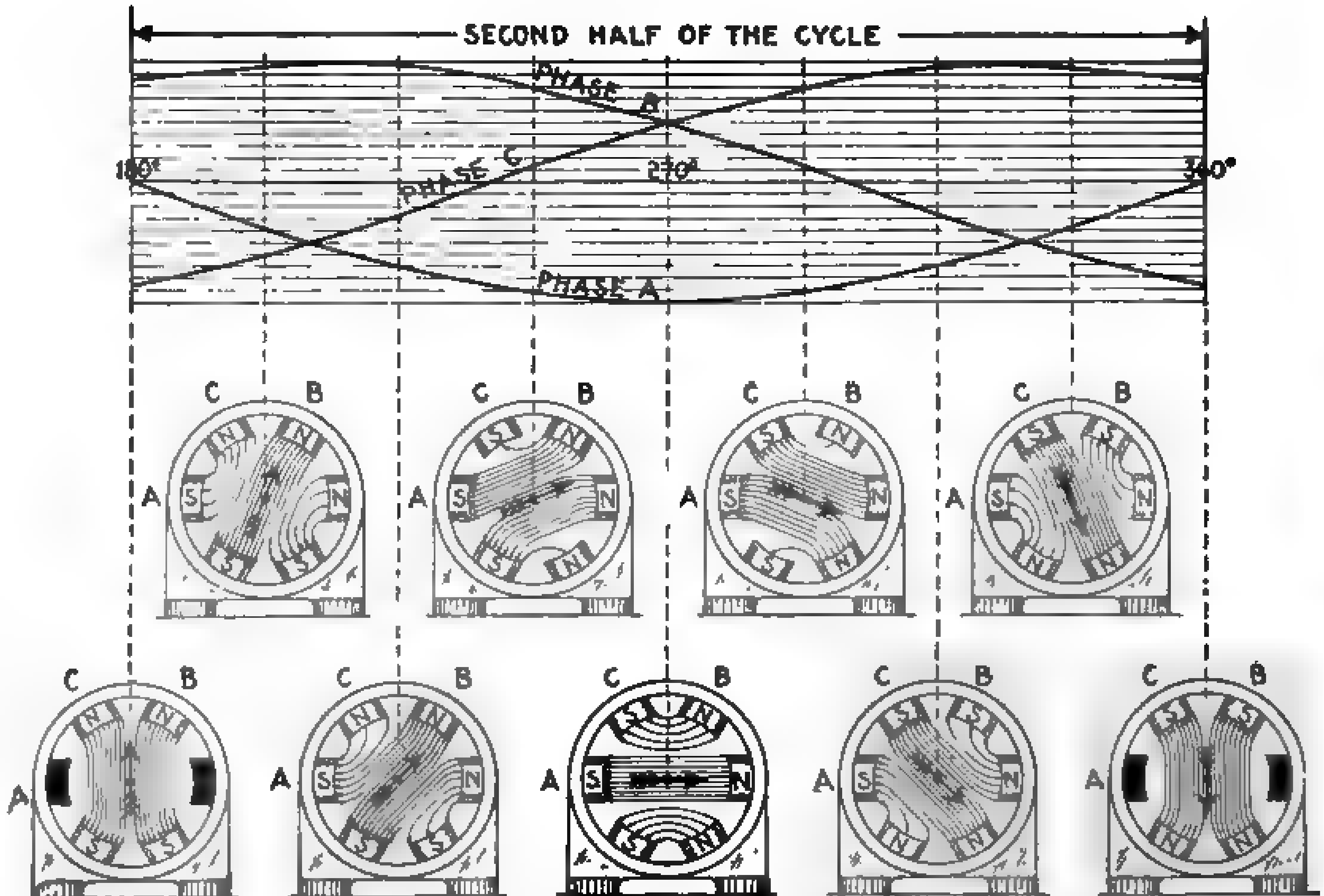


FIG. 1,688.—Production of three phase rotating magnetic field with winding on laminated iron ring. The winding is divided into twelve sections, which are connected in three groups, A, B, and C, of four sections each, the sections in each group being evenly placed round the ring with the sections of the two other groups between them. One end of each group is to be connected to the line wire and the other end to the common junction J, from which it follows that the winding given is an example of "star" winding. With three phase currents the winding will give at every instant four N poles and four S poles round the ring, and in actual working these poles will be on the inner periphery because of the presence of an inner ring or cylinder of good magnetic iron placed, with the requisite clearance to allow of rotation, as close as is mechanically possible to the outer ring. Each one of these eight poles will make a complete revolution round the ring in four times the periodic time of the currents supplied. Thus, if the supply current has a frequency of 50, a complete revolution of the field will take place in .08 (= $^4/_{50}$) of a second, which corresponds to an angular velocity of 750 revolutions per minute in place of 3,000 revolutions per minute, which would be the angular velocity with a bi-polar field at this periodicity. Similarly a continuously wound Gramme ring tapped at twelve points, joined in three groups of four each to the supply mains, would give an eight pole rotary field. In this case the grouping would be a "*mesh*" grouping, with each side of the mesh formed of four coils in parallel.



FIGS. 1,699 to 1,708.—Sine curves of three phase current and diagrams showing the physical conception of a three phase rotating magnetic field. The diagrams are constructed in the same manner as explained in figs. 1,664 to 1,682. It should be noted that the phase windings are arranged in the direction of rotation in the sequence ACB, phase C being wound in opposite



sense to A and B, as indicated by the curves, in that north poles are produced at A and B when the respective curves are above the zero line, a south pole being produced at C when its curve is above the zero line. The rotation of the resultant magnetization is clearly seen by following the arrow through its successive positions.

Slip.—Instead of the magnetic needle as was used in the preceding figures, a copper cylinder may be placed in a rotating magnetic field and it will be urged also to turn in the same direction as the rotation of the field.

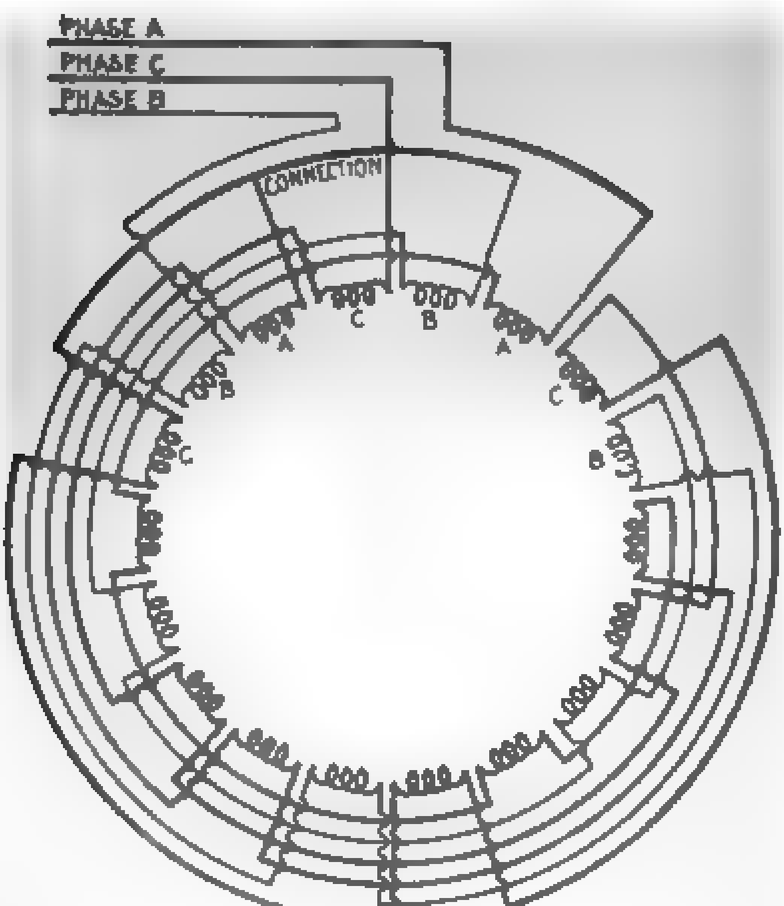


FIG. 1,709.—Diagram of three phase, six pole field winding. There are 18 groups, and the sequence of phases is ABC in a counter clockwise direction. For a Y connection, the middle phase is reversed, so that a pole will be formed by the three consecutive phases when the current is in the same direction in A and C, and opposite in B. The beginning of the middle coil C, and not the end, as with the other two, is connected to the common point O. In this case the pole shifts a distance equal to three groups for each alternation, so that one revolution of the field requires three cycles.

The torque tending to turn the cylinder is due to the induction of currents of opposite polarity in the cylinder.

For simplicity, the rotating magnetic field may be supposed to be produced by a pair of magnetic poles placed at opposite sides of the cylinder and *revolved around it* as in fig. 1,710.

Now, for instance in starting, the cylinder being at rest any element or section of the surface as the shaded area A B, will, as it comes into the magnetic field of the rotating magnet, cut

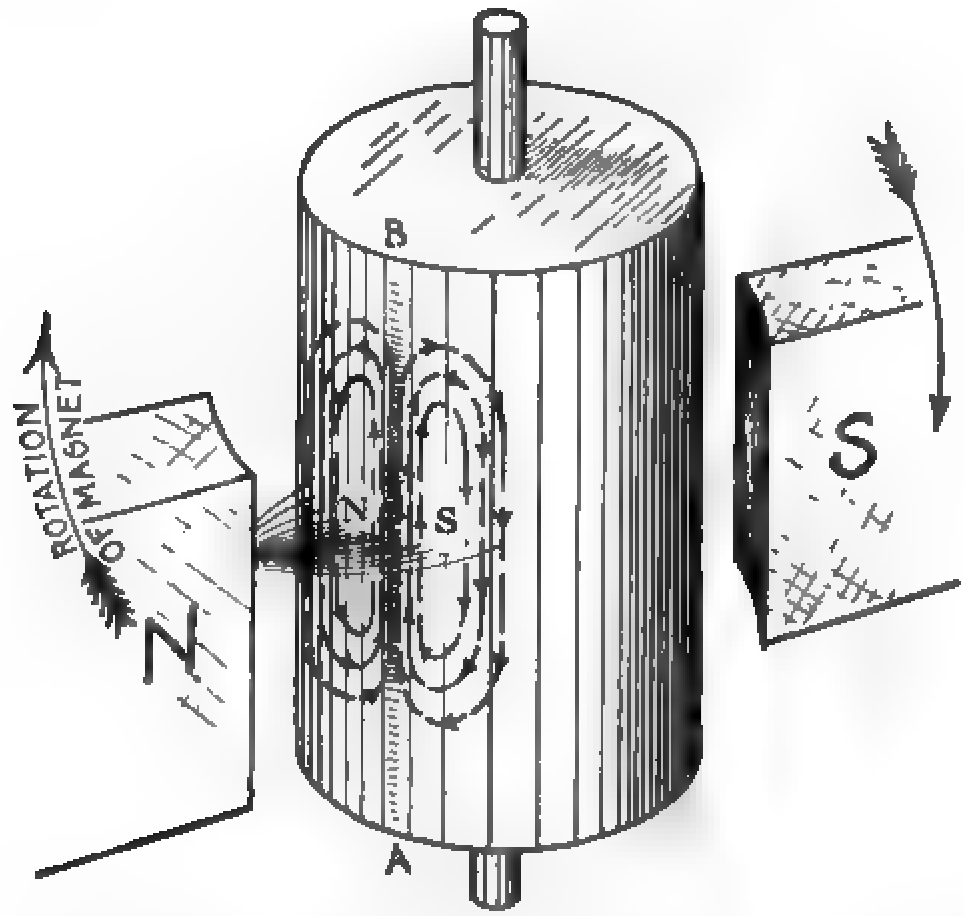
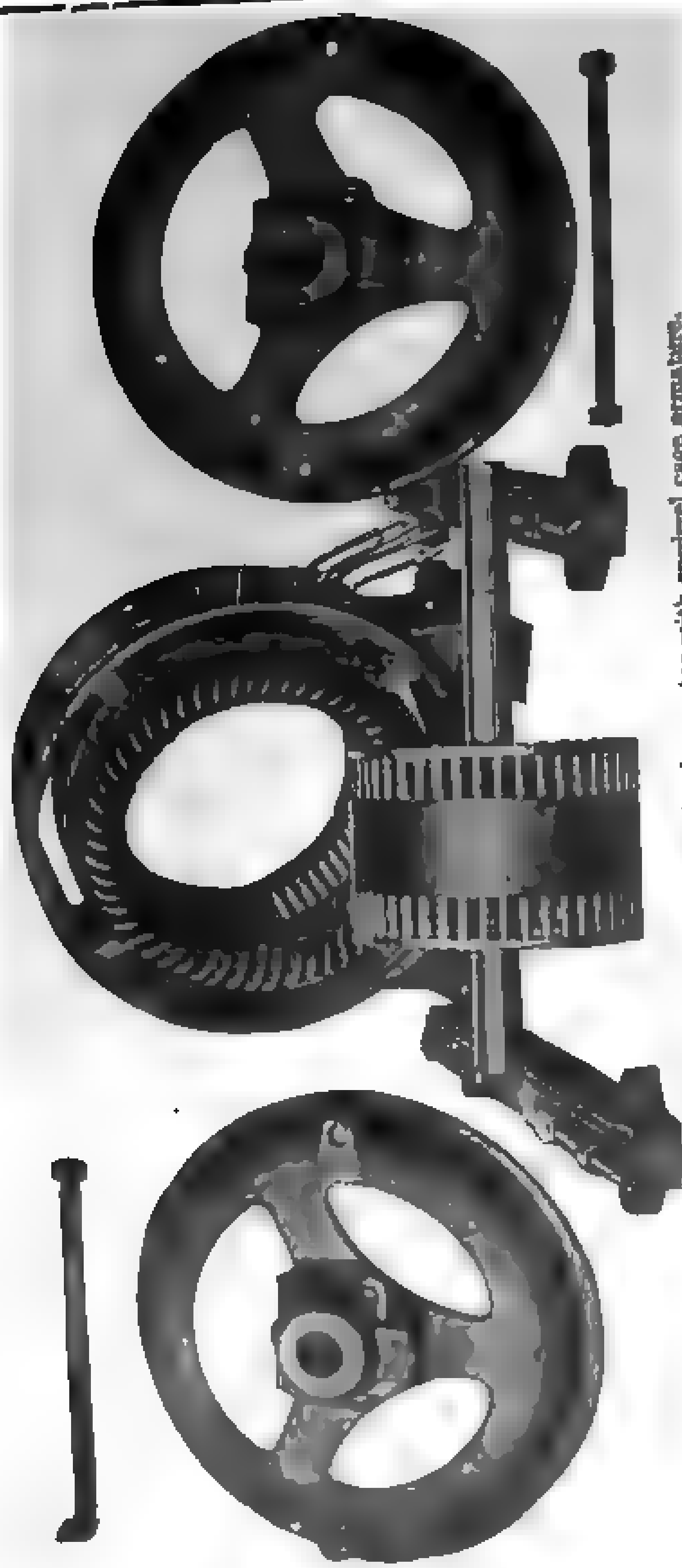


FIG. 1,710.—Copper cylinder and rotating magnet *illustrating the principle of operation of an induction motor*. The "rotating magnetic field" which is necessary for induction motor operation is for simplicity here produced by rotating a magnet as shown. In starting, the cylinder being at rest, any element as AB, as it is swept by the field will cut magnetic lines, which will induce a current upward in direction as determined by applying Fleming's rule (fig. 132, page 133). The inductive action is strongest at the center of the field hence as AB passes the center the induced pressure along AB is greater than along elements more or less remote on either side. Accordingly a pair of eddy currents will result as shown (see fig. 201, page 271) Applying the right hand rule for polarity of these eddy currents (see fig. 119, page 117) it will be seen that a S pole is induced by the eddy on the side of the cylinder receding from the magnet, and a N pole by the eddy on the side toward which the magnet is approaching. The cylinder, then, is *attracted* in the direction of rotation of the magnet by the induced pole on the receding side, and *repelled* in the same direction by the induced pole on the approaching side. Accordingly, the cylinder begins to rotate. The velocity with which it turns depends upon the load; it must always turn *slower* than the magnet, in order that its elements may cut magnetic lines and induce poles to produce the necessary torque to balance the load. The difference in speed of the magnet and cylinder is called the *slip*. Evidently the greater the load, the greater is the slip required to induce poles of sufficient strength to maintain equilibrium. The figure is drawn somewhat distorted, so that both eddies are visible.



FIGS. 1,711 to 1,718.—Parts of Allis-Chalmers polyphase induction motor with squirrel cage armature.

magnetic lines of force inducing a current therein, whose direction is easily determined by applying Fleming's rule.

Since the field is not uniform, but gradually weakens, as shown, on either side of the shaded area (which is just passing the center), the pressure induced on either side will be less than that induced in the shaded area, giving rise to eddy currents (as illustrated in

NOTE.—In order to avoid confusion in applying Fleming's rule, it may be well to regard the pole as being stationary and the cylinder as in motion; for, since motion is "purely a relative matter" (see fig. 1,393), the inductive action will be the same as if the pole stood still while the cylinder revolved from left to right, that is, counter clockwise, looking down on it. Regarding it thus (pole stationary and cylinder revolving counter clockwise) Fleming's rule (see fig. 132, page 133) is easily applied to ascertain the direction of the induced current, which is found to flow upward in the shaded area as shown.

fig. 291, page 271). These eddy currents induce poles as indicated at the centers of the whorls, the polarity being determined by applying the right hand rule (fig. 119, page 117).

By inspection of fig. 1710, it is seen that *the induced pole toward which the magnet is moving is of the same polarity as the magnet; therefore it is* **repelled**, *while the induced pole from which the magnet is receding, being of opposite polarity, is* **attracted.** *A torque is thus produced tending to rotate the cylinder.*

It must be evident that this torque is greatest when the cylinder is at rest, because the magnetic lines are cut by any element on the cylindrical surface at the maximum rate.

Moreover, as cylinder is set in motion and brought up to speed, the torque is gradually reduced, because the rate with which the magnetic lines are cut is gradually reduced.

Ques. What is the essential condition for the operation of an induction motor?

Ans. The armature, or part in which currents are induced, must rotate at a speed slower than that of the rotating magnetic field.

In the elementary induction motor, fig. 1,710, the cylinder is the armature, and the rotating magnets are the equivalent of a rotating magnetic field.

Ques. What is the difference of speed called?

Ans. *The slip.*

Ques. Why is slip necessary in the operation of an induction motor?

Ans. If the armature had no weight and there was no friction offered by the bearings and air, it would revolve in synchronism with the rotating magnetic field, that is, the slip would be zero, but since weight and friction are always present and constitute

a small load, its speed of rotation will be a little less than that of the rotating magnetic field, so that induction will take place, in amount sufficient to produce a torque that will balance the load.

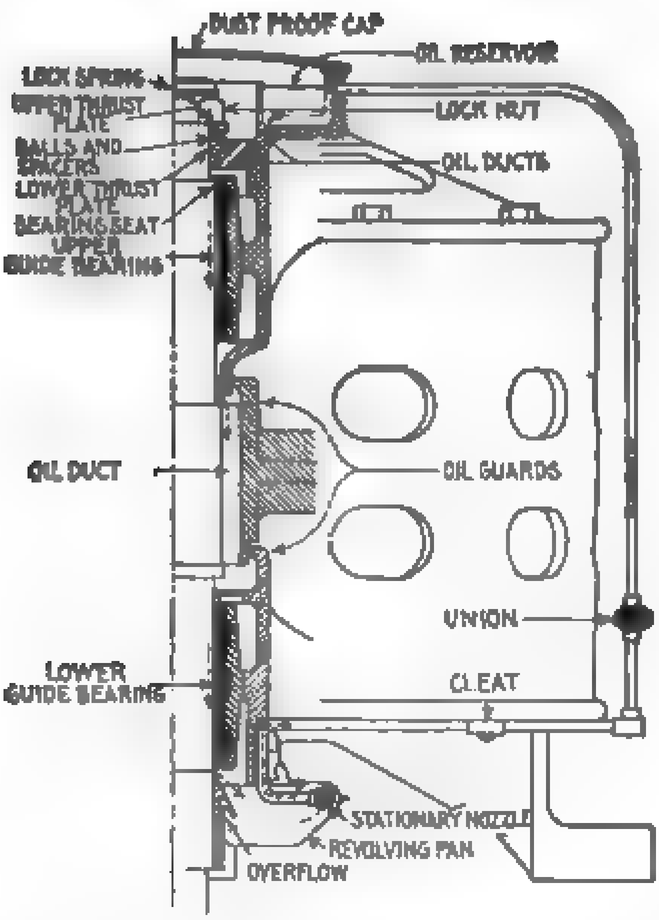


FIG. 1,719.—General Electric vertical type induction motor, sectional view showing oiling system. It is provided with ball thrust bearings and top and bottom guide bearings, and a continuous flow of oil is maintained through all the bearings by means of a pump which is made integral with the motor. The ball thrust bearings are designed to support the weight of the armature only. In cases where the armature is direct connected a flexible coupling should be used to prevent additional weight coming on the thrust bearings. In operation, when the motor starts, the oil, revolving with the pan, flows against the stationary nozzle and is forced by its velocity at a high pressure through the oil pipe into the reservoir on top. It then flows down through the ball bearing and upper guide bearing, through a slot in the armature spider into the lower guide bearing and thence into the oil pan. Thus a continuous stream of oil is delivered through all bearings.

Ques. How is slip expressed?

Ans. In terms of synchronism, that is, as a percentage of the speed of the rotating magnetic field.

The slip is obtained from the following formula:

$$\text{Slip (rev. per sec.)} = S_f - S_a$$

or, expressed as a percentage of synchronism, that is, of the synchronous speed,

$$\text{Slip (\%)} = \frac{(S_f - S_a) \times 100}{S_f}$$

where

S_f = Synchronous speed, or R.P.M. of the rotatory magnetic field;
S_a = Speed of the armature.

FIG. 1,720.—Triumph back geared polyphase induction motor. A great many applications, especially for direct attachment, require the use of either a very slow or special speed motor. As these are quite costly, the preferable arrangement, and one equally as satisfactory, is the use of a standard speed motor combined with a back geared attachment. Rawhide pinions are furnished whenever possible, insuring smooth running with a minimum of noise.

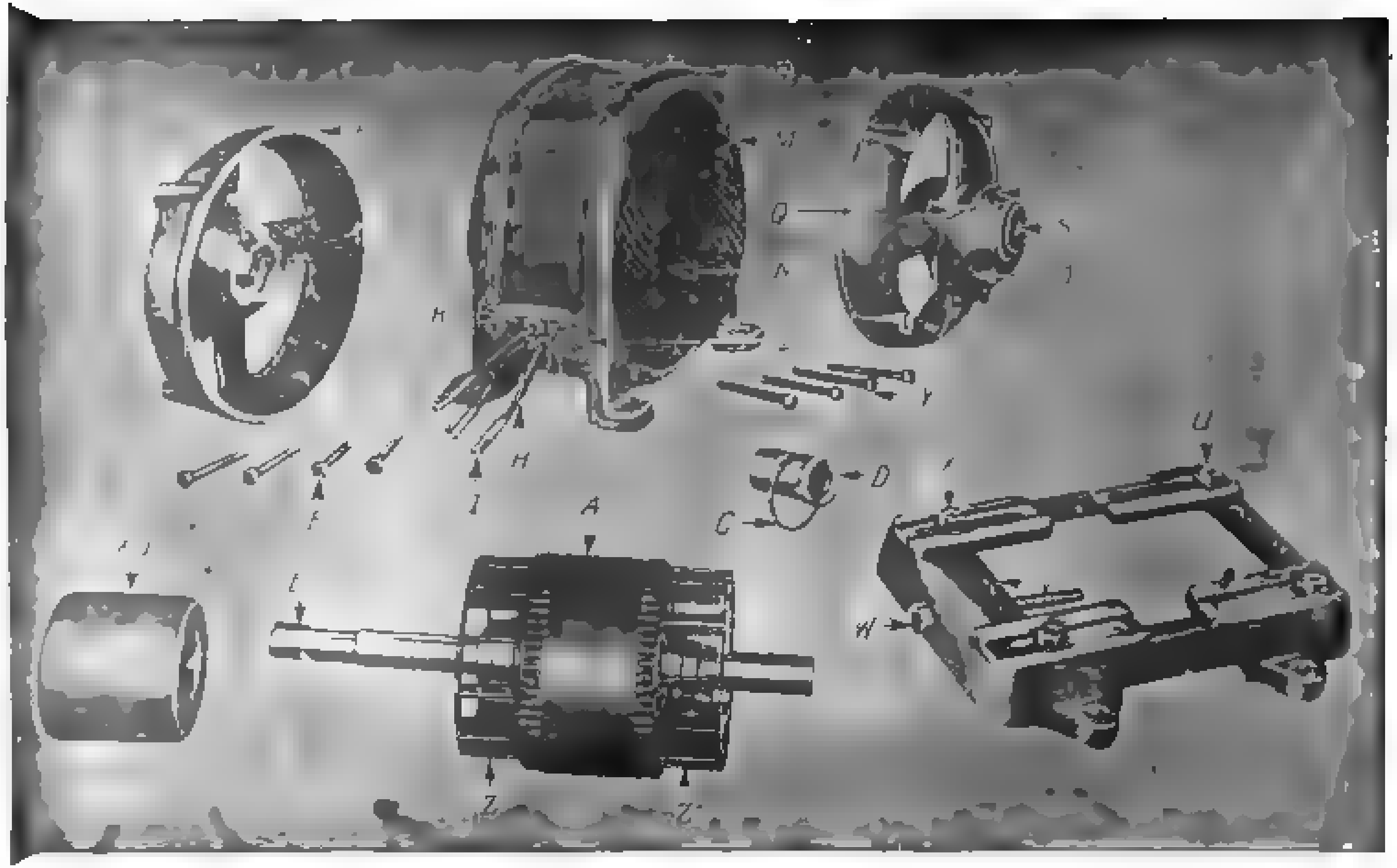
The synchronous speed is determined the same as for synchronous motor by use of the following formula:

$$S_f = \frac{2f}{P}$$

where

S_f = Synchronous speed or R.P.M. of the rotating magnetic field;
P = Number of poles;
f = frequency.

[redacted]



FIGS. 1,721 to 1,735.—Parts of General Electric small polyphase induction motors. A, armature; B, key for armature shaft; C, oil ring; D, bearing lining; E, bearing head, pulley end; F, cap screw for bearing heads; G, field, complete with winding, terminal plate and leads; H, motor leads; I, terminal connector for motor leads; J, soft rubber bushing for motor leads; K, terminal plate; L, screw for terminal board; M, field coils; N, wooden top sticks for field coils; O, oil filler; P, bearing head opposite pulley end; Q, screw for oil well cover; R, oil well cover; S, socket pipe plug for bearing head; U, motor base; V, yoke for motor base; W, motor base adjusting screw; X, bolt for motor base and frame (short); Y, cap screw for bearing head; Z, internal directive fan; Aa, pulley.

The following table gives the synchronous speed for various frequencies and different numbers of poles:

Table of Synchronous Speeds

Frequency	R.P.M. of the rotating magnetic field, when number of poles is					
	2	6	10	16	20	24
25	1,500	500	300	188	150	125
60	3,600	1,200	720	450	360	300
80	4,800	1,600	960	600	480	400
100	6,000	2,000	1,200	750	600	500
120	7,200	2,400	1,440	900	720	600
125	7,500	2,500	1,500	938	750	625

Ques. How does the slip vary?

Ans. It varies from about 1 per cent. in a motor designed for very close regulation to 40 per cent. in one badly designed, or designed for some special purpose.

Ques. Why is the slip ordinarily so small?

Ans. Because of the very low resistance of the armature, very little pressure is required to produce currents therein, of sufficient strength to give the required torque. Hence, the necessary rate of cutting the magnetic lines to induce this pressure in the armature is reached with very little difference between the field speed and armature speed, that is, with very little slip.

Ques. How does the slip vary with the load?

Ans. The greater the load the greater the slip.

In other words, if the load increase, the motor will run slower, and the slip will increase. With the increased slip, the induced currents and the driving force will further increase. If the motor be well designed *so that the field strength is constant* and the lag of the armature *currents is small*, the driving force developed or torque will be pro*portional to the slip*, that is the slip will increase automatically as t *load is increased*, so that the *torque* will be proportional to the load.

According to Weiner, the slip varies according to the following table:

SLIP OF INDUCTION MOTORS

Capacity of motor H. P.	Slip at full load per cent.		Capacity of motor H. P.	Slip at full load per cent.	
	Usual limits	Average		Usual limits	Average
1/8	20 to 40	30	15	5 to 11	8
1/4	10 " 30	20	20	4 " 10	7
1/2	10 " 20	15	30	3 " 9	6
1	8 " 20	14	50	2 " 8	5
2	8 " 18	13	75	1 " 7	4
3	8 " 16	12	100	1 " 6	3.5
5	7 " 15	11	150	1 " 5	3
7½	6 " 14	10	200	1 " 4	2.5
10	7 " 12	9	300	1 " 3	2

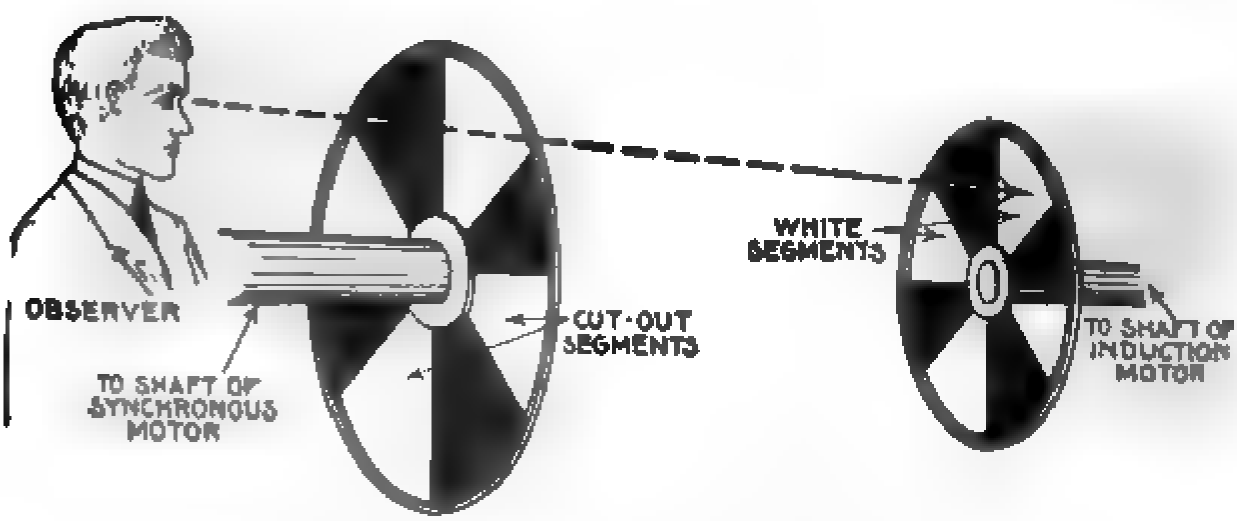


FIG. 1,786.—Sector method of measuring the slip of induction motors. A black disc having a number of white sectors (generally the same as the number of poles of the induction motor) is fastened with wax to shaft of the induction motor, and is observed through another disc having an equal number of sector shaped slits (that is a similar disc with the white sectors cut out) and attached to the shaft of a small self-starting synchronous motor, which is fitted with a revolution counter that can be thrown in or out of gear at will; then the slip (in terms of N_r) = $N + (N_s + N_r)$, in which: N = number of passages of the sectors; N_s = number of sectors; N_r = number of revolutions recorded by the counter during the interval of observation. For large values of slip, the observations may be *simplified by using only one sector* (N_s = 1), then N will equal the slip in revolutions.

Ques. Describe one way of measuring the slip.

Ans. A simple though rough way is to observe simultaneously the speed of the armature and the frequency, calculating the slip from the data thus obtained, as on page 1,315.

This method is not accurate, as, even with the most careful readings, large errors cannot be avoided. A better way is shown in fig. 1,736.

FIG. 1,737.—Detail of Westinghouse squirrel cage armature for induction motor. This is an example of *cast on* construction similar to that of Morse-Fairbanks (see figs. 1,752, 1,753 and 1,915). The inductors are embedded in a special cement.

Evolution of the Squirrel Cage Armature.—In the early experiments with rotating magnetic fields, copper discs were used; in fact, it was then discovered that *a mass of copper or any conducting metal, if placed in a rotating magnetic field, will be urged in the direction of rotation of the field.*

Ferraris used a copper cylinder as in figs. 1,710 and 1,738, which was the first step in the evolution of the squirrel cage armature. The trouble with an armature of this kind is that there is no definite path provided for the induced currents.

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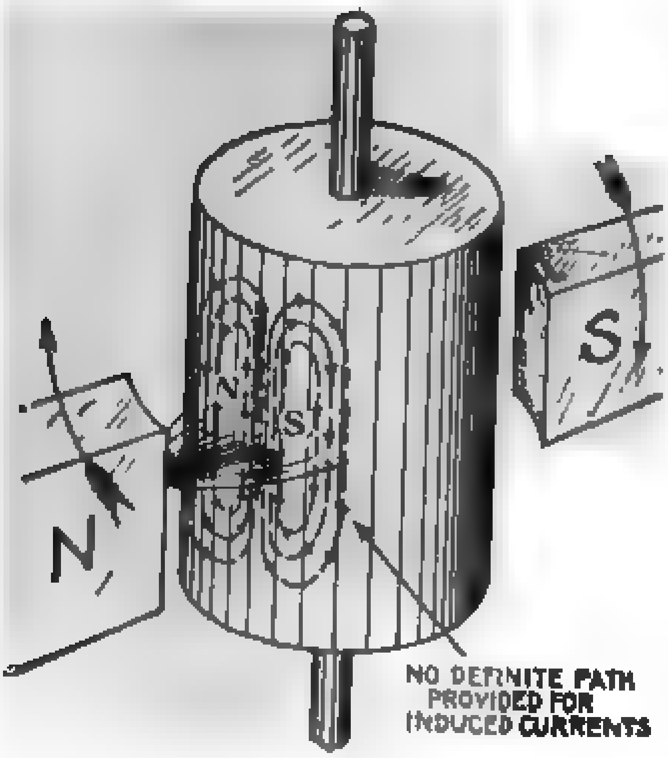
S
N
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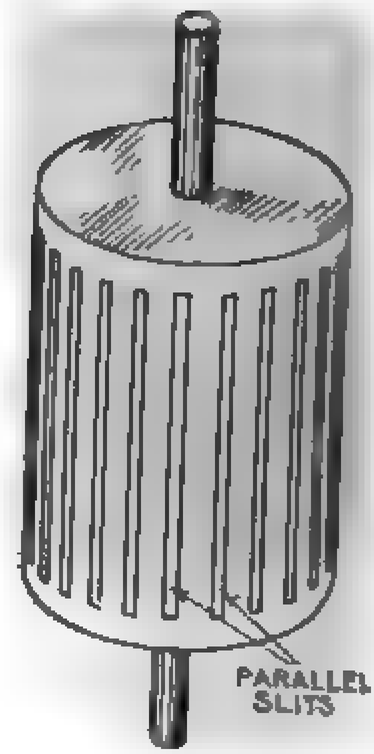
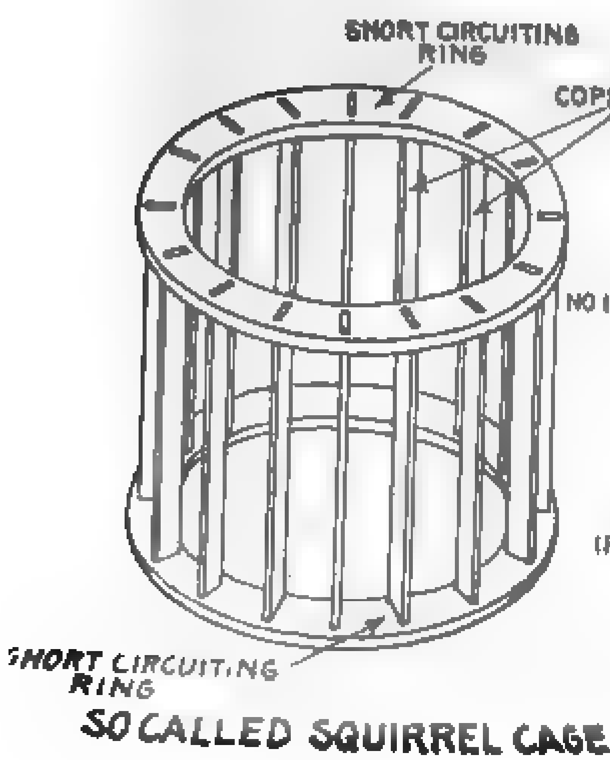
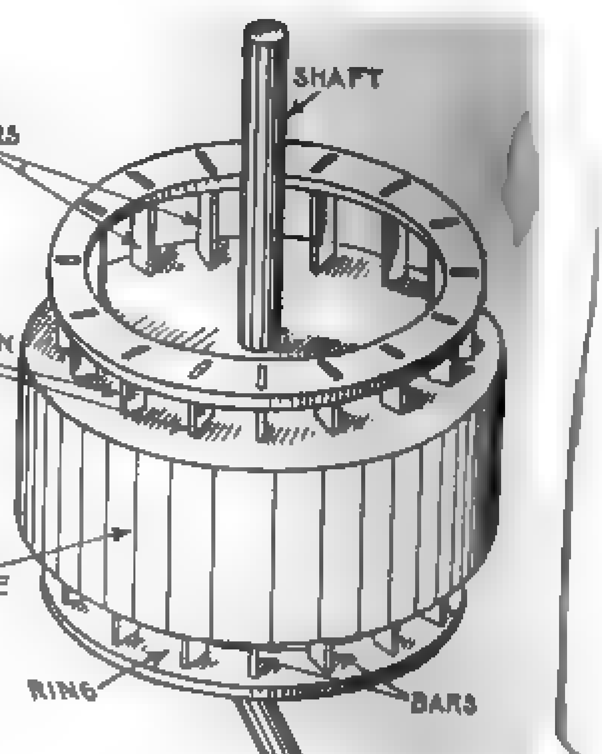
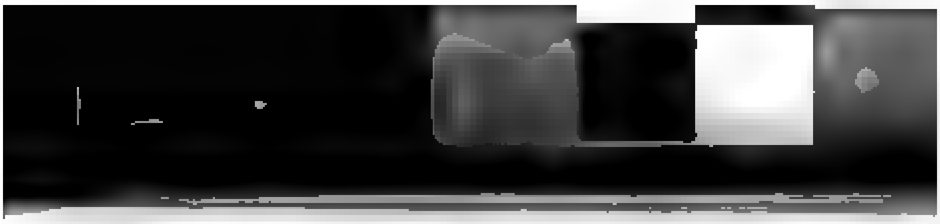
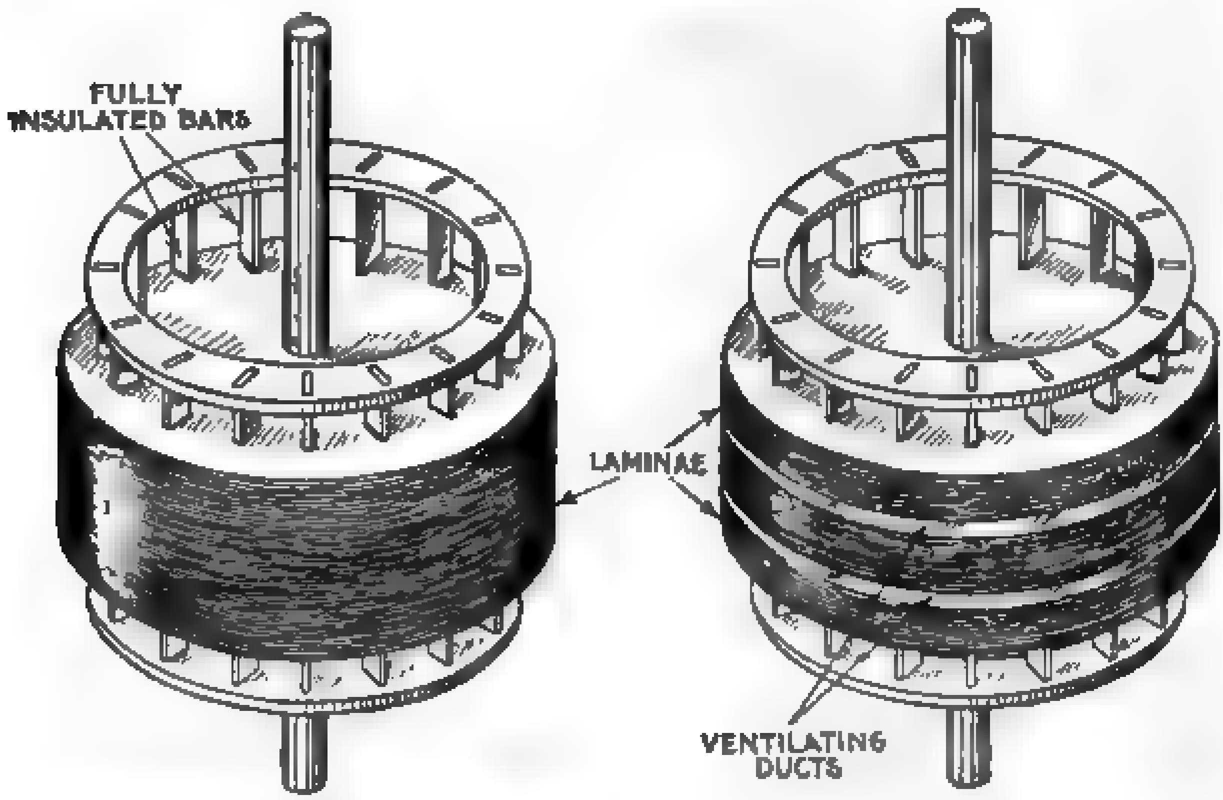
NO DEFINITE PATH PROVIDED FOR INDUCED CURRENTS


PARALLEL SLITS


SHORT CIRCUITING RING
COPPER BARS
SHORT CIRCUITING RING
SO CALLED SQUIRREL CAGE


SHAFT
NO INSULATION
SOLID IRON CORE
RING
BARS





FIGS. 1,738 to 1,744.—Evolution of the squirrel cage armature. The early experiments of Arago, Herschel, Babbage and Baily demonstrated that a mass of copper or any conducting metal, if placed in a revolving magnetic field, will be urged to revolve in the direction of the revolving field. They used discs, but Ferraris used a copper cylinder as shown in figs. 1,710 and 1,738; this was the first squirrel cage armature. Figs. 1,739 to 1,744 show the gradual development of the primitive device shown in fig. 1,738. fig. 1,739, Ferraris' cylinder with slots restricting the path of induced currents; fig. 1,740, Dobrowolsky's so called squirrel cage which he embedded in a solid iron core, as in fig. 1,741; fig. 1,742, design with insulated bars and laminated core to prevent eddy currents in the core; fig. 1,743, laminated core with ventilating ducts; fig. 1,744, modern squirrel cage armature representing the latest practice as built by Mechanical Appliance Co. The core is built up of discs punched from No. 29 gauge electrical sheet, insulated from each other and firmly clamped between end plates locked on the shaft. The slots in the discs are of the same general form as those in the core. Heavy fibre end pieces, punched to match the discs are placed at each end of the core, to prevent the bars coming in contact with the sharp edges of the teeth. The winding is made up of rectangular copper bars, passing through slots in the core, and short circuited on each other by means of copper end rings of special design. The bars are pressed into holes punched in the end rings, and the contact is then protected from corrosion by being dipped in a solder bath. The bars are insulated from the iron of the core by fibre cell projecting beyond the end of the slot. To secure ventilation the short circuiting rings are set some distance from the end of the core. In this way the bars between the core and the ring act as the vanes of a pressure blower, forcing a large volume of air through the field coils and ventilating openings.

Obviously, a better result is obtained if, in fig. 1,738, the downward returning currents of the eddies are led into some path where they will return across a field of opposite polarity from

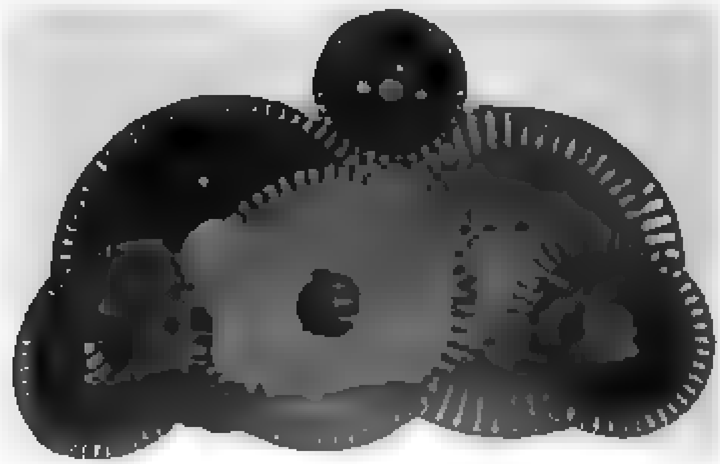


FIG. 1,745.—Mechanical Appliance Co. solid core discs as used on small and medium size induction motors.

FIG. 1,746.—Allis-Chalmers squirrel cage armature construction. The core laminae are mounted on a cast iron spider having arms shaped to act as fan blades for forcing air through the motor. The spider is pressed on to the shaft. In the smallest sizes the punchings are mounted directly on the shaft, which is properly machined to hold them firmly. Copper bars are used as inductors in the larger sizes, and copper rods in the smaller sizes. *The ends of* the inductors are turned down somewhat smaller than the body and fit in *holes in the end* rings. The shoulder thus formed fits firmly against the end rings. Good *electrical contact* is obtained by expanding the inductors in the end ring holes. In large *armatures both* bars and end rings are of rectangular cross section, the bars and rings *being fastened* by machine steel cap screws.

that across which they ascended, as in such case, the turning effect will be doubled. Accordingly the design of fig. 1,738 was modified by cutting a number of parallel slits which extended nearly to the ends, leaving at each end an uninterrupted "ring" of metal. This may be called the first squirrel cage armature, and in the later development Dobrowolsky was the first to employ a built-up construction, using a number of bars joined together by a ring at each end, as in fig. 1,740, and embedded in a solid

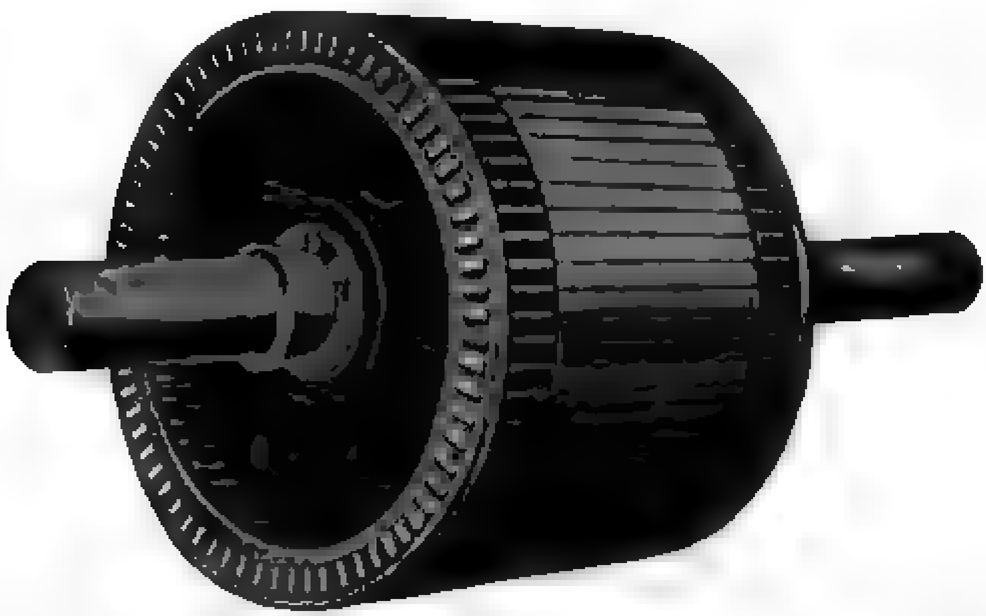


Fig. 1,747.—Triumph squirrel cage armature. In construction thin sheet steel laminations, japanned, are built up to form the core, and are rigidly clamped together by heavy malleable iron end plates. Semi-enclosed slots are punched in the outer periphery to receive the windings, so that none of the centrifugal force is carried by the inductors. These inductors are set edge on, and are riveted and soldered into resistance rings. These rings are punched to receive the inductors in such a manner that there is an unbroken strip of metal completely surrounding them. Moreover, the short circuiting rings are set some distance from the end of the core, so that the inductors between the core and ring act as vanes to force air through the coils for ventilation.

mass of iron, as in fig. 1,741; he regarding the bars merely as veins of copper lying buried in the iron.

A solid cylinder of iron will of course serve as an armature, as it is magnetically excellent; but the high specific resistance of iron prevents the flow of induced currents taking place sufficiently copiously; hence *a solid cylinder of iron is improved by surrounding it with a mantle of copper, or by a squirrel cage of copper bars (like fig. 1,740), or*

[redacted]

Fig. 1,748.—General Electric soldered form of end ring construction on squirrel cage armatures. The armature inductors or copper bars laid in the core slots are short circuited by these end rings, which are also made of copper. For the smaller sizes the rings are thin, but of considerable radial depth and are held apart by spacing washers. They have rectangular holes punched near their outer peripheries through which the bars pass. Lips are formed on the rings, as shown, to which the bars are soldered.

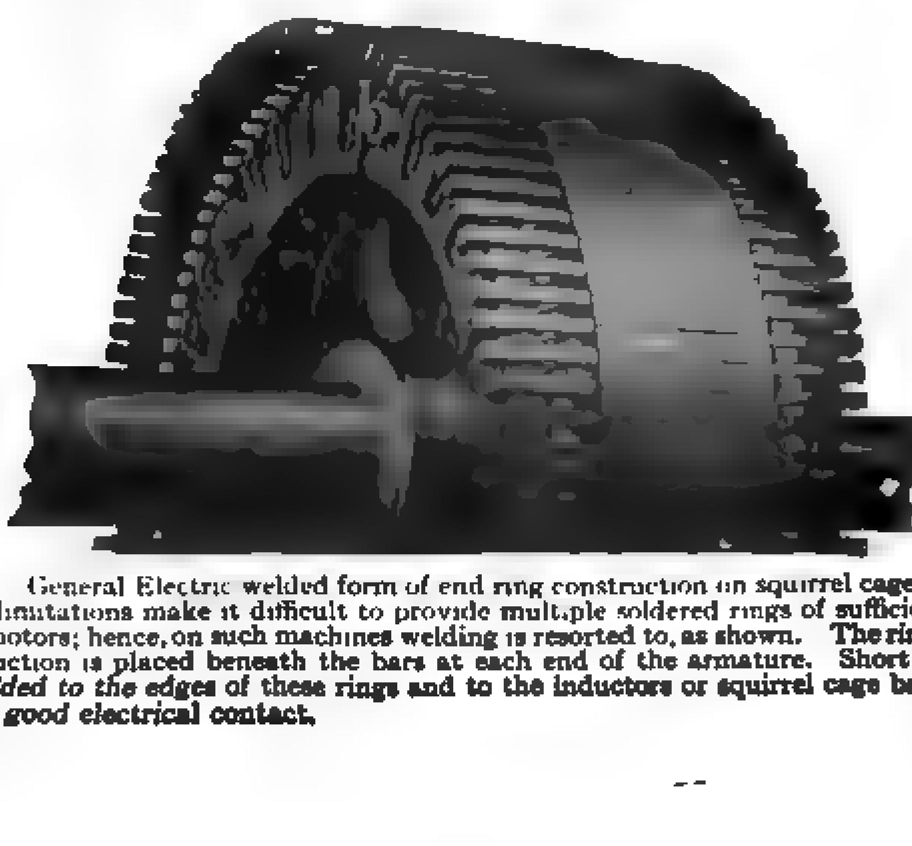
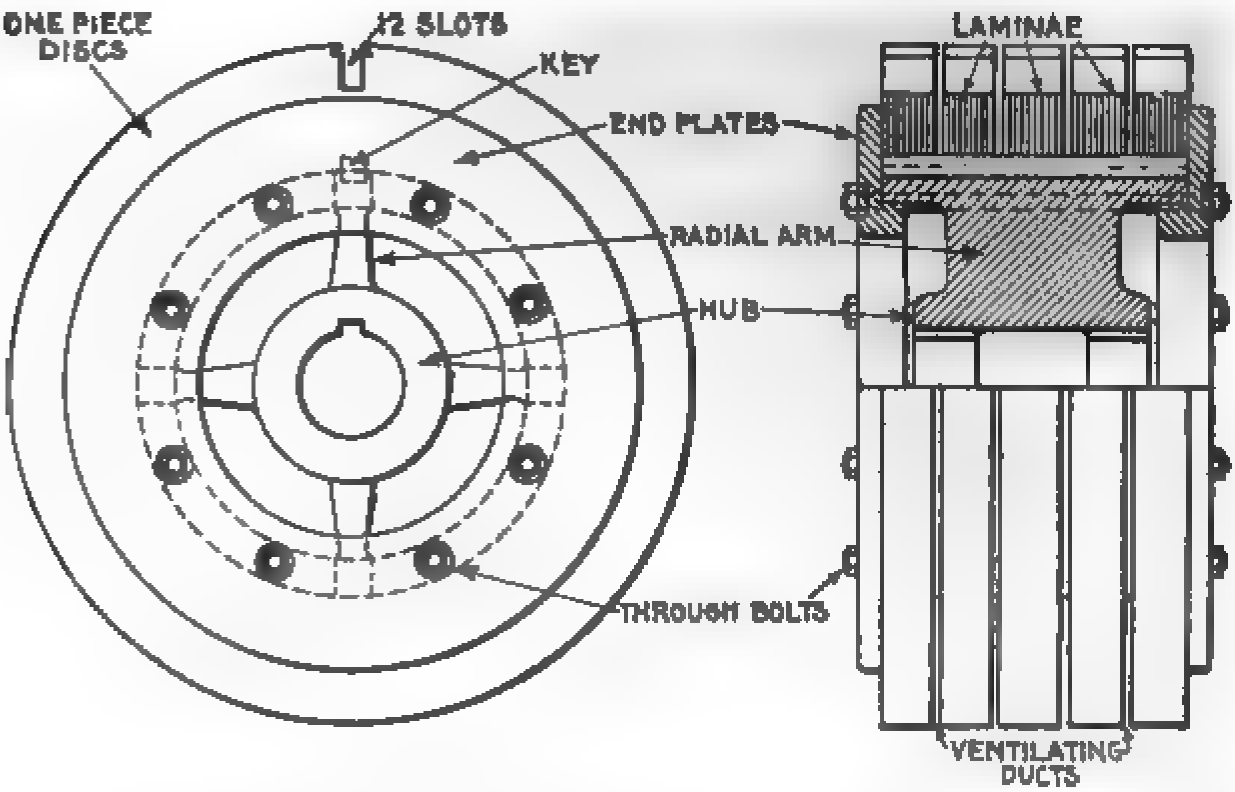


Fig. 1,749.—General Electric welded form of end ring construction on squirrel cage armatures. Space limitations make it difficult to provide multiple soldered rings of sufficient area for large motors; hence, on such machines welding is resorted to, as shown. The ring in welded construction is placed beneath the bars at each end of the armature. Short radial bars *are welded to the edges* of these rings and to the inductors or squirrel cage bars, thereby *making good* electrical contact.

[redacted]

embedding rods of copper (short circuited together at their ends with rings) in holes just beneath its surface. However, since all eddy currents that circle round, as those sketched in fig. 1,738, are not so efficient in their mechanical effect as currents confined to proper paths, and as they consume power and spend it in heating effects, the core was then constructed with laminations lightly insulated from each other, and further the squirrel cage copper bar inductors were fully insulated from contact with the core. Tunnel slots were later replaced by designs with open tops.



FIGS. 1,750 and 1,751.—Built up core construction with discs punched in one piece. The spider proper consists of a hub provided with four radial arms which fit the inner diameter of the disc. The hub is bored out so that it fits very tightly on the shaft, and a key is provided to avoid any chance of turning. The core disks are clamped firmly in place by two heavy cast iron end plates which are pressed up and held by the bolts. These bolts pass under the discs, so that there is no danger of their giving rise to eddy currents. The key not only prevents the discs turning on the spider but also ensures the alinement of discs, which is necessary to make the teeth form smooth slots when the core is assembled.

Fig. 1,744 shows a modern squirrel cage armature conforming to the latest practice, other designs being illustrated in the numerous accompanying cuts.

In the smaller sizes, the core laminæ are of the solid type as shown in fig. 1,745, but for larger motors the core consists of a spider and segmental discs as shown in figs. 1,750 and 1,751.

Fig. 1,748 shows a soldered form of end ring construction, and figs. **1,752 and 1,753 the method of welding the end ring to the inductors.**

The Field Magnets.—The construction of the field magnets, which, when energized with alternating current produce the rotating magnetic field, is in many respects identical with the armature construction of revolving field alternators.

FIG. 1,752.—Fairbanks-Morse squirrel cage armature with cast-on rings showing inspection grooves. The method consists in fusing the ends of the inductors into an end ring of a special composition, thereby producing a *perfect electrical and mechanically strong joint.* In this process the armature with its bars in place is put into a mould and the molten metal poured around the inductors, melting their ends and effectually fusing them into the body of the ring. The ring is then turned down to finished size and polished. An inspection groove is cut as shown to indicate that the fusion is complete and the joint perfect.

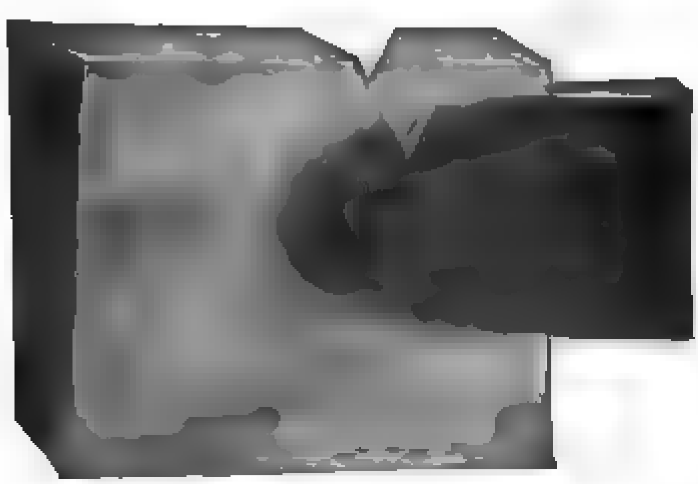


FIG. 1,753.—Section of Fairbanks-Morse "cast-on" joint showing union of end ring and inductor. The view shows the V-shape inspection groove as described in fig. 1,752.

Broadly, the field magnets of induction motors consists of:

1. Yoke or frame;
2. Laminae, or core stampings;
3. Winding.

FIG. 1,754.—Richmond field construction for polyphase induction motors, showing style of winding for use with squirrel cage and wound armature types.

Ques. What is the construction of the yoke and laminae?

Ans. They are in every way similar to the armature frame and core construction of revolving field alternators.

***Field Windings* for Induction Motors.**—*The field wind ings of induction* motors are almost always made to produ

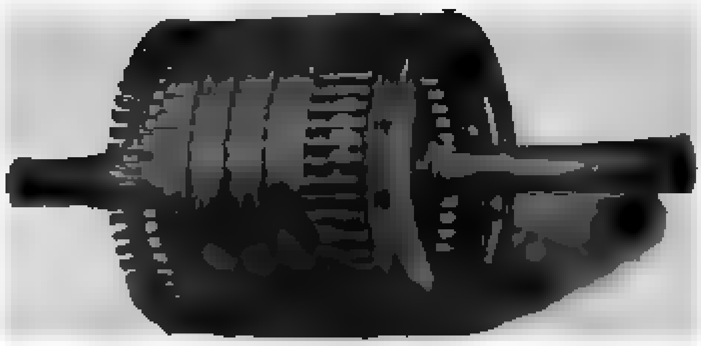


FIG. 1,755.—Western Electric squirrel cage armature of high speed induction motor for centrifugal pump service. This armature is an example of heavy duty construction. The inductors are welded to the short circuiting end rings, the latter being located beneath the inductors, as shown. Fan vanes are provided at one end for ventilation. In the field construction, the core laminations are assembled in a closed box frame, and clamped by heavy rings while under hydraulic pressure. The stator coils are form wound and subjected to a special insulating process, which renders them especially impervious to moisture, and capable of operating without breakdown in locations which are too damp for ordinary motors. The bearing brackets are of rigid mechanical construction, and the pulley end bracket and bearings of all sizes are split to facilitate removal of the rotor and complete inspection. These machines range in size from 50 to 200 horse power, the rugged construction adapting them to heavy and severe service, such as is met with in mining, the construction of dams, canals, aqueducts, tunnels, etc.

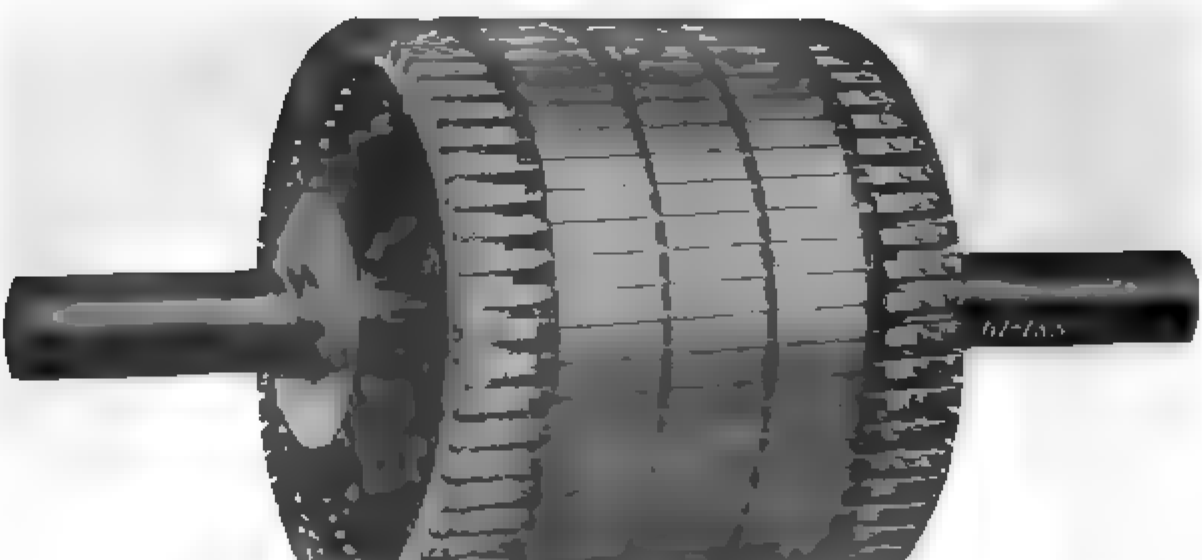


FIG. 1,756.—Wagner squirrel cage armature for polyphase induction motor, as employed on motors of from 5 to 25 horse power. The features of construction as seen in the illustration are bar inductors, ventilating passages through the core laminae, riveted connection between inductors and end rings ventilating vanes on end plate, extra large end rings. The object of making the rings unusually large is to make the resistance of the rings lower than is desirable for some classes of service, in order to obtain motors having minimum slip, increased efficiency, and maximum overload capacity under normal operation. When the torque required by some very unusual and entirely abnormal installation exceeds that of the average conditions, it is an easy matter to reduce the section of the end rings, by *turning them down* in a lathe, thereby increasing the resistance and starting torque.

more than two poles in order that the speed may not be unreasonably high. This will be seen from the following:

If P be the number of *pairs* of poles per phase, *f*, the frequency, and N, the number of revolutions of the rotating field per minute, then

$$N = \frac{60 \times f}{P}$$

Thus for a frequency of 100 and one pair of poles, $N = 60 \times 100 \div 1 = 6{,}000$. By increasing the number of pairs of poles to 10, the fre-

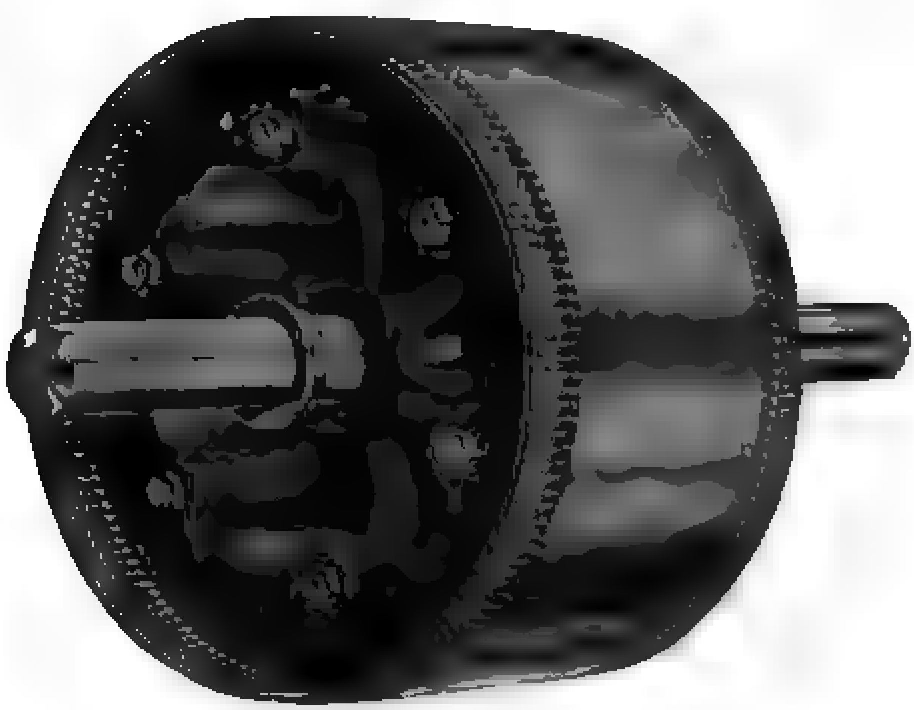


FIG. 1,757.—Richmond squirrel cage armature. The copper bars are double riveted at either end to the resistance rings, then dipped into a solder bath.

quency remaining the same, $N = 60 \times 100 \div 10 = 600$. Hence, in design, by increasing the number of pairs of poles the speed of the motor is reduced.

Ques. State an objection to very high speed of the rotating field.

Ans. The more rapid the rotation of the field, the greater is the starting *difficulty.*

Ques. Besides employing a multiplicity of poles, what other means is used to reduce the speed?

Ans. Reducing the frequency.

Ques. What difficulty is encountered with low frequency currents?

Ans. If the frequency be very low, the current would not be suitable for incandescent lamp lighting, because at low frequency the rise and fall of the current in the lamps is perceptible.

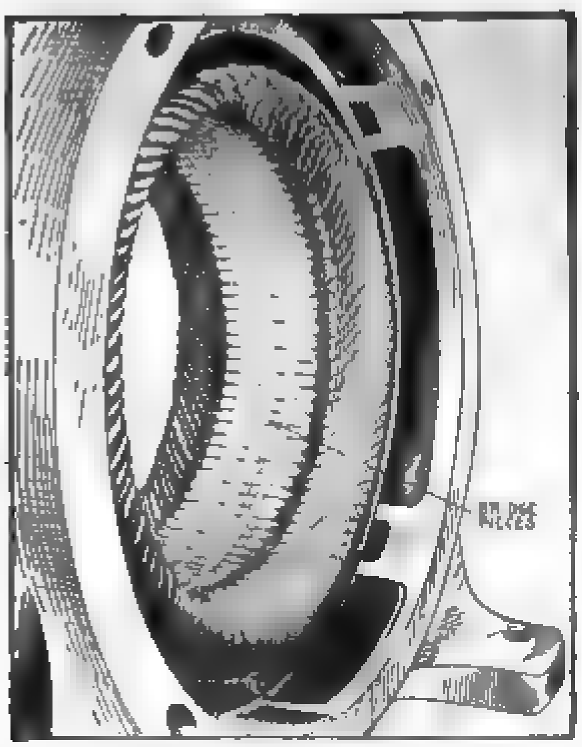


FIG. 1,758.—Field construction of Crocker Wheeler induction motor with *magnetic bridge*. Steel bridges are inserted in the grooves where the coils are placed, to protect them from dirt and mechanical injury and at the same time provide a path for the magnetic flux which has a more uniform reluctance, thereby insuring a better distribution of the flux in the air gap and at the same time retaining open slot construction from which the coils can be readily removed.

Ques. What is the general character of the field winding?

Ans. The field core slots contain a distributed winding of substantially the same character as the armature winding of a revolving field polyphase alternator.

Ques. Are the poles formed in the usual way?

Ans. They are produced by properly connecting the groups of coils and not by windings concentrated at certain points on salient or separately projecting masses of iron, as in direct current machines.

Ques. How are the coils grouped?

Ans. Three phase windings are usually Y connected.

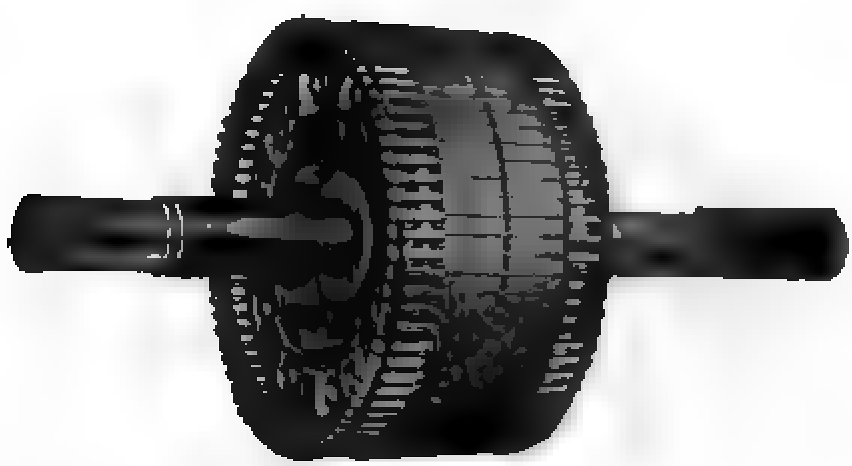


FIG. 1,759.—Western Electric squirrel cage armature. The inductors consist of solid copper bars embedded in the slots of a laminated core, with their projecting ends securely fitted and soldered to heavy copper rings.

Ques. What other arrangement is sometimes used?

Ans. In some cases Y grouping is used for starting and Δ grouping for running.

Starting of Induction Motors.—It must be evident that if the field winding of an induction motor whose armature is at rest, be connected directly in the circuit without using any starting device, the machine is placed in the same condition as a transformer with the secondary short circuited and the primary connected to the supply circuit. Owing to the very low resistance

of the armature, the machine, unless it be of very small size, would probably be destroyed by the heat generated before it could come up to speed. Accordingly some form of starting device is necessary. There are several methods of starting, as with:

1. Resistances in the field;
2. Auto-transformer or compensator;
3. Resistance in armature.

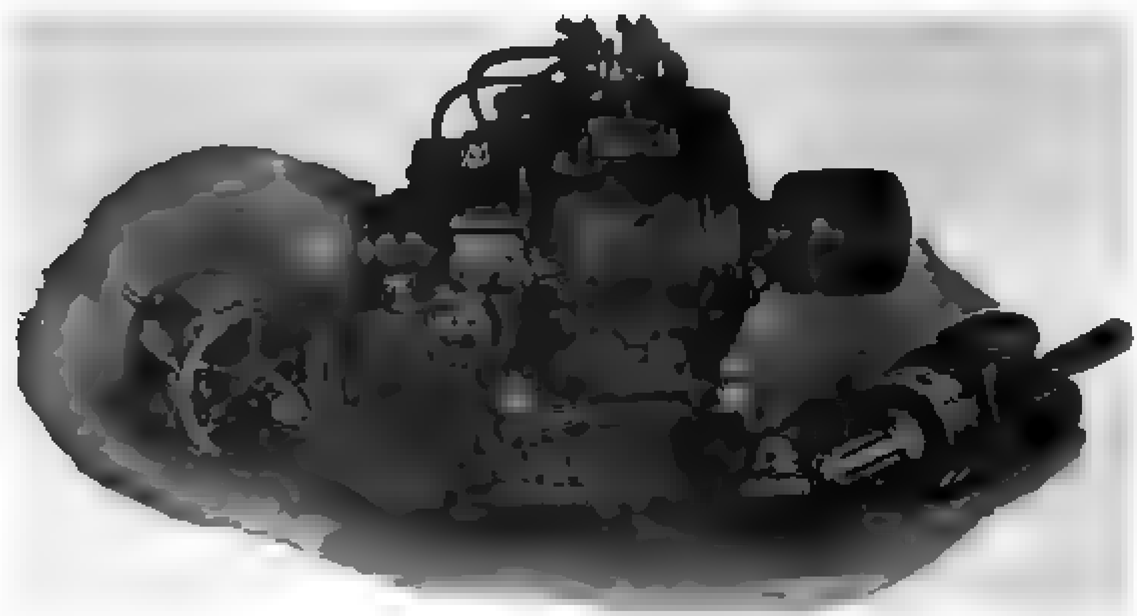


FIG. 1,760.—Holtzer Cabot combination polyphase induction motor set, consisting of wound frame and three rotors: 1, squirrel cage armature, 2, wound armature, 3, rotating field. The set is intended for school demonstration of induction motor phenomena. The motor operating with the squirrel cage armature has an inherent constant speed characteristic and on brake tests will show its exceptionally strong starting torque and ability to take excessive overloads. This motor can be used as a generator also, in the sense that if connected to the line and driven above synchronous speed by some external means, it will act as an asynchronous generator and return power to the line. For variable speed service, an armature having a winding upon it similar to that on the frame must be used. External resistances inserted in the armature circuit may be used to produce, first, a reduction of starting current, second, an increase of starting torque, or third, a variation of speed. Thus an extensive list of experiments can be performed with this phase wound armature directly along the line of present engineering practice. The phase wound armature can be used as an alternator in the same sense as mentioned above for the squirrel cage machine. For synchronous motor and three phase operation the revolving field with projecting poles and slip rings would be used, the field being excited from a direct current supply.

Ques. Explain the method of inserting resistances in the field.

Ans. Variable resistances are inserted in the circuits leading *to the field* magnets and mechanically arranged so that the

resistances are varied simultaneously for each phase in equal amounts. These starting resistances are enclosed in a box similar to a direct current motor rheostat.

Ques. Is this a good method?

Ans. It is more economical to insert a variable inductance in the circuit, by using an auto-transformer.

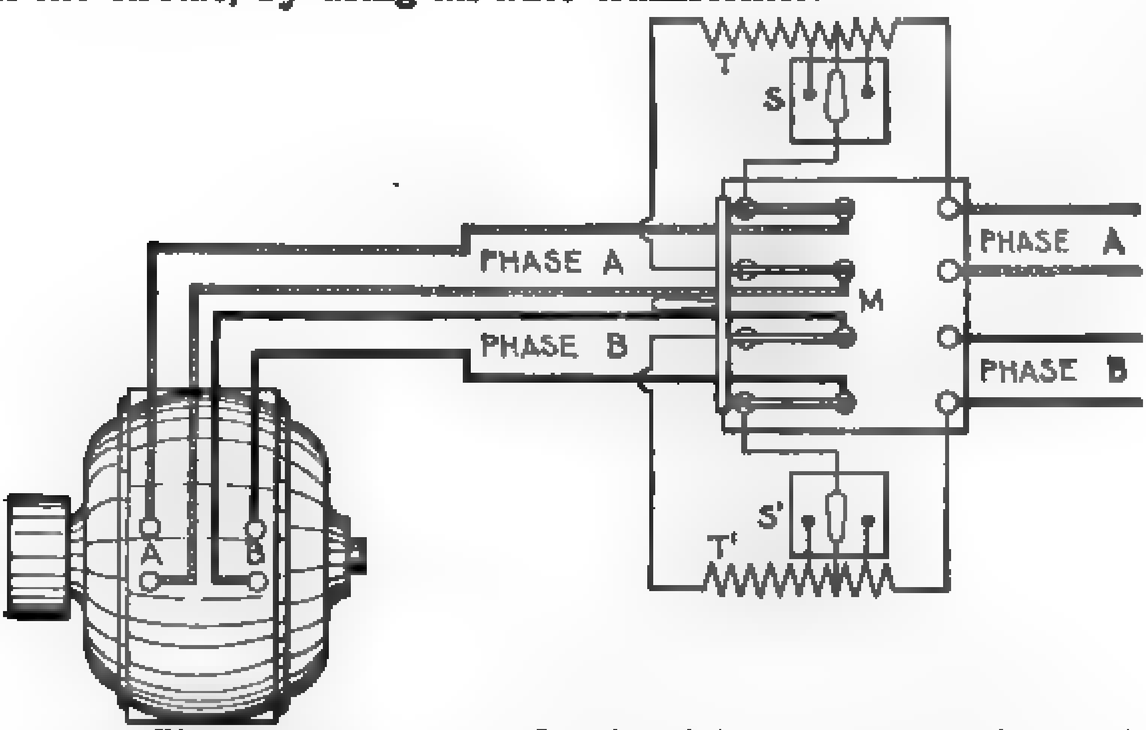


FIG. 1,761.—Westinghouse auto-starter. Polyphase induction motors may be started by connecting them directly to the circuit with an ordinary switch, and the smaller motors are started in this way in practice. In the larger motors, however, the starting torque at normal voltage is several times its full load torque; therefore, they are started on a reduced voltage, and the full pressure of the circuit is not applied until they have practically reached their operating speed. The figure shows connections with a two phase alternating current circuit. The auto-starter consists of two auto-transformers T and T', each having only a single winding for both primary and secondary, which are tapped at certain points by switches, thus dividing the winding into a number of loops, so that one of several voltages may be applied for starting, and the starting torque thus adjusted to the work that has to be performed. At the highest points tapped by the switches S, and S', the full pressure, and at the lowest points, the lowest pressure, is applied to the motor by the operation of the main switch M. This switch has four blades and three positions. When thrown to the left as indicated, it connects the auto-transformers T and T', across the circuits A and B respectively, so that the pressure across the transformer coils, as determined by the position of the switches S and S', is applied to the motor circuits A and B. The intermediate position of the switch M interrupts both circuits. To start the motor, the switch M is thrown to the left and a reduced pressure applied; after the motor has started and come up to speed the switch M is thrown to the right, thus cutting out the transformer and connecting the motor directly to the circuit. The starting device can be located at a point remote from the motor, thus eliminating danger from fire due to possible sparks, in case where it is necessary to install the motors in grain elevators, woolen mills, or in any place exposed to inflammable gases, or floating particles of combustible matter. This feature is also valuable in cases where motors are suspended from the ceiling, or installed in places not easily accessible.

Ques. What is the auto-transformer or compensator method of starting?

Ans. It consists of reducing the pressure at the field terminals by interposing an impedance coil across the supply circuit and feeding the motor from variable points on its windings.

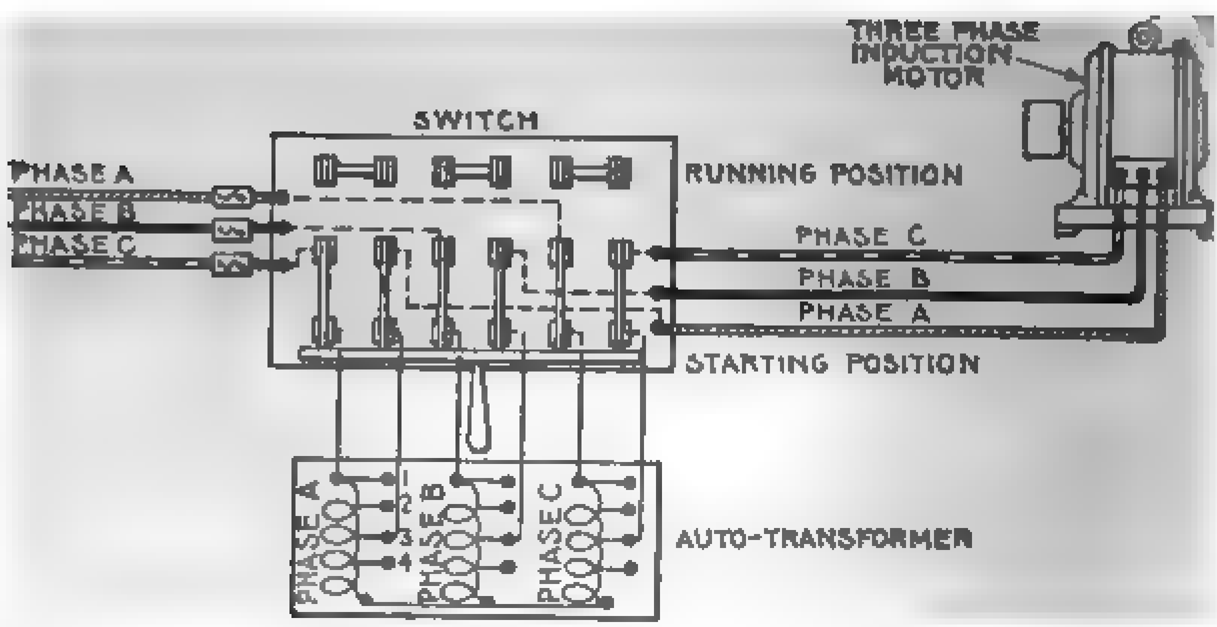


FIG. 1,762.—Auto-transformer or compensator connections for three phase induction motor. In operation when the double throw switch is thrown over to starting position, the current for each phase of the motor flows through an auto-transformer, which consists of a choking coil for each phase, arranged so that the current may be made to pass through any portion of it (as 1, 2, 3) to reduce the voltage to the proper amount for starting. After the motor has come up to speed on the reduced voltage, the switch is thrown over to running position, thus supplying the full line voltage to the motor. *In actual construction fuses are usually connected, so that they will be in circuit in the running position, but not in the starting position, where they might be blown by the large starting current.

Internal Resistance Induction Motors.—The armature of this type of induction motor differs from the squirrel cage variety in that the winding is not short circuited through copper rings, but, in starting, is short circuited through a resistance mounted directly on the shaft in the interior of the armature.

When the motor is thrown in circuit, a very low starting current is drawn from the line due to the added resistance in the armature. As the motor comes up to speed, this resistance is gradually cut out, and at full speed the motor operates as a squirrel cage motor, with short circuited winding.

*NOTE.—The construction of starting devices for induction motors is fully explained later, the accompanying cuts serving merely to illustrate the principles involved.

Ques. How is the resistance gradually cut out in internal resistance motors?

Ans. By operating a lever which engages a collar free to slide horizontally on the shaft. The collar moves over the internal resistance grids (located within the armature spider), thus gradually reducing their value until they are cut out.

FIG. 1,763.—View of armature interior of Wagner polyphase induction motor with wound armature, showing the centrifugal device which at the proper speed short circuits all the coils, transforming the motor to the squirrel cage type. The winding is connected with a vertical "commutator" so called. Inside the armature are two governor weights, which are thrown outwards by the centrifugal force when the machine reaches the proper speed, thus pushing a solid copper ring (which encircles the shaft) into contact with the inner ends of the "commutator" bars, thus completely short circuiting the armature winding.

Ques. For what size motors is the internal resistance method suited?

Ans. Small motors.

Ques. Why is it not desirable for large motors?

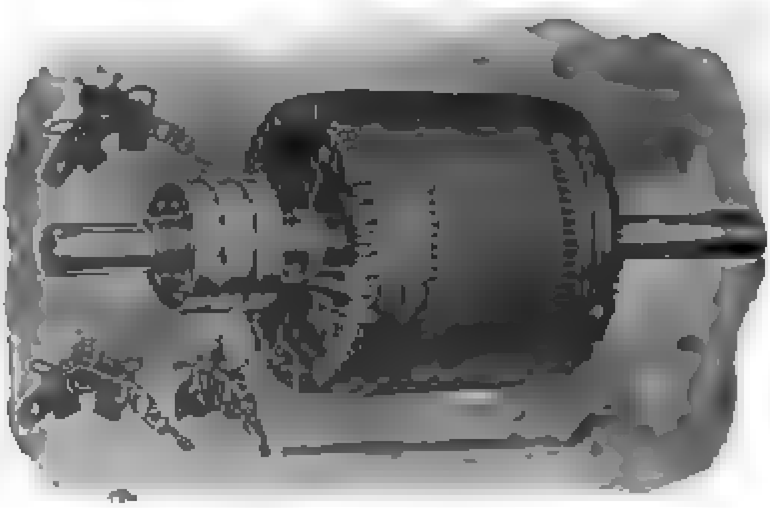
Ans. The excessive I^2R loss in the resistances, if confined within the armature spider, would produce considerable heating, and on this account it is best placed external to the motor.

Ques. On what class of circuit are internal resistance motors desirable?

Ans. On circuits devoted to lighting service as well as power service, where a high degree of voltage regulation is essential.

The initial rush of current when a squirrel cage motor is thrown on the line is more or less objectionable and there are central stations which allow only resistance type of induction motor to be used on their lines.

FIG. 1,764.—Western Electric wound armature for internal resistance induction motor. In starting the inductors are short circuited through a resistance which is gradually cut out as the motor comes up to speed.



FIGS. 1,765 to 1769.—Western Electric wound armature for external resistance, or slip ring induction motor, showing brush rigging, slip rings and bar winding.

***External* Resistance or Slip Ring Motors.**—In large *machines,* and those which must run at variable speed, such as *is required* in the operations of cranes, hoists, dredges, etc., it i

advisable that the regulating resistances be placed externally to the motor. Motors having this feature are commercially known as **slip ring motors**, because *connections are made between the external resistances and the armature inductors by means of slip rings.*

FIG. 1,770.—Richmond slip ring motor.

As with the internal resistance motor the armature winding of a slip ring motor is not short circuited through copper rings in starting, but through a resistance, which in this case is located externally.

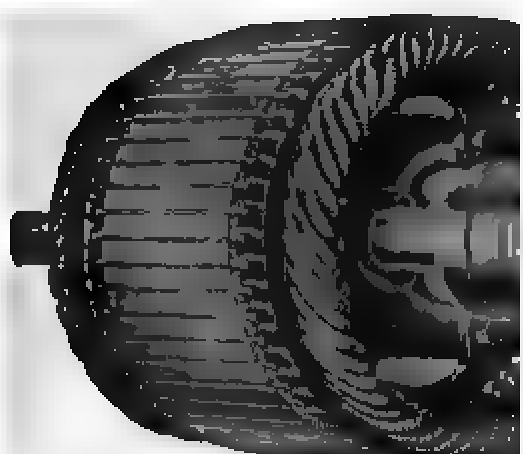


FIG. 1,771.—Richmond slip ring armature as used on motor in fig. 1,770.

Ques. How is the armature winding connected?

Ans. It is connected in Y grouping and the free ends connected to the slip rings, leads going from the brushes to the

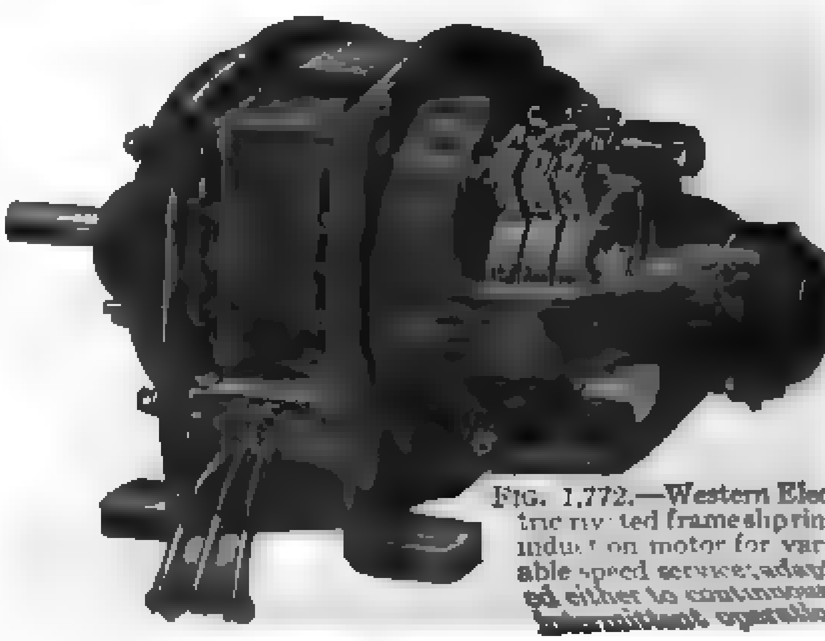


FIG. 1,772.—Western Electric riveted frame slip ring induction motor for variable speed service; adapted either to continuous or intermittent operation.

variable external resistances, these being illustrated in fig. 1,778.

Single Phase Induction Motors.—The general utility of single phase motors, particularly the smaller sizes, is constantly

FIGS. 1,773 to 1,778.—Sprague skeleton type motor frame with various types of armature. Fig. 1,777, plain squirrel cage armature; fig. 1,778, internal resistance armature; fig. 1,773 slip ring armature. In the construction of the plain squirrel cage armature, fig. 1,777, copper bars are inserted in the slots of the core, and are insulated from the core by enclosing tubes which project about one-half inch beyond the iron at each side. The bars are short circuited at their ends by copper rings. These rings are thin, but of considerable radial depth and are held apart by spacing washers. They have rectangular holes punched near their outward periphery, through which the armature bars pass, and to which they are soldered. The internal resistance armature, fig. 1,778, is provided with a phase winding, starting (internal) resistance, and switch located on the shaft. The starting resistance is designed to give approximately full load torque with full load current at starting. A greater torque than full load torque can be obtained for starting if required, by cutting out resistance. The resistance consists of cast iron grids enclosed in a triangular cover which is bolted to the end plates holding the armature laminæ together, and is short circuited by sliding laminated spring metal brushes along the inside surface of the grids. The brushes are supported by a metal sleeve sliding on the shaft which is operated by a lever secured to the bearing bracket and located just above the bearing. A rod passing through the end of the shaft operates the short circuiting arrangement in sizes up to about 25 horse power. *The external resistance or slip ring armature, fig. 1,773, is similar in construction to fig. 1,778, with the exception that slip rings are provided because of the external location of the resistance.* These rings connect the inductor through brushes to a controlling and *external resistance*, two or more carbon brushes being provided for each ring, as in fig. 1,773.

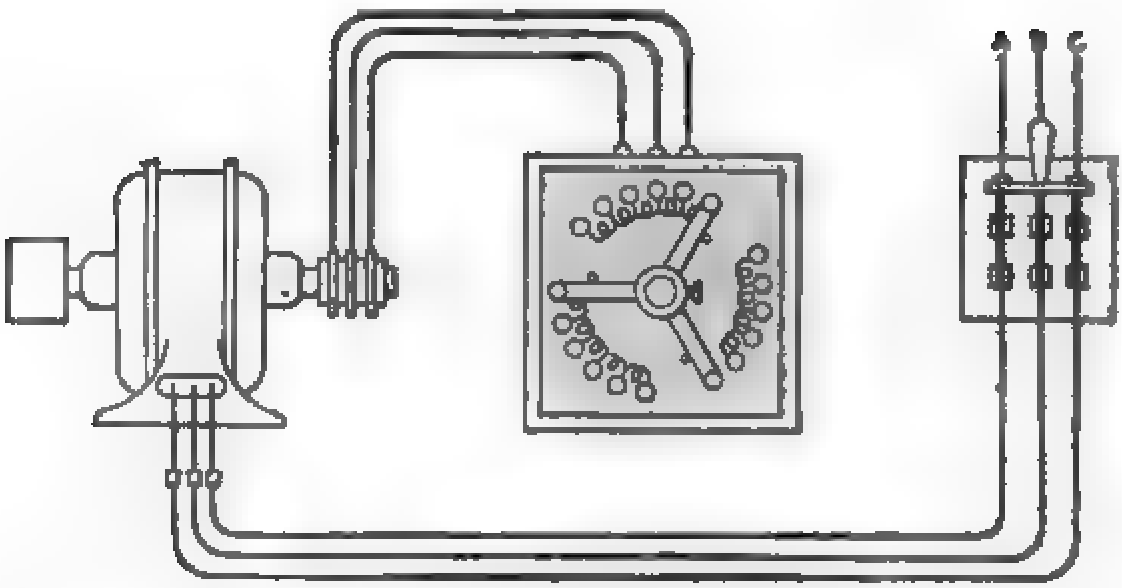
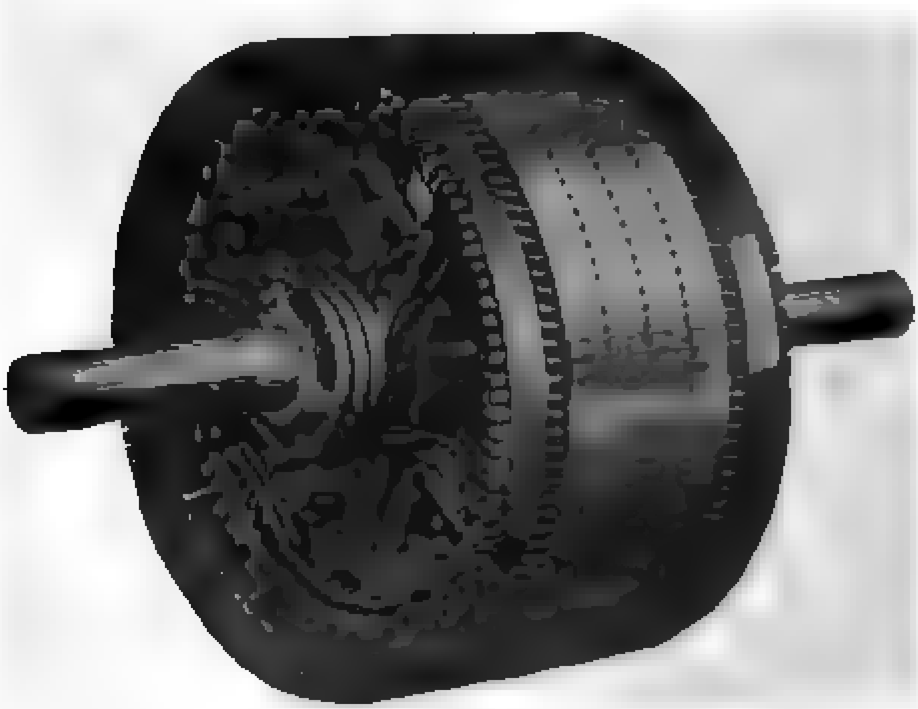


FIG. 1,779.—External resistance or slip ring induction motor connections. The squirrel cage armature winding is not short circuited by copper end rings, but connected in Y grouping and the three free ends connected to three slip rings, leads going from the brushes to three external resistances, arranged as triplex rheostat having three arms rigidly connected as shown, so that the three resistances may be varied simultaneously and in equal amounts.



00.—Allis-Chalmers phase wound external resistance type or slip ring armature con- ction. The winding is for three phases and the terminals are brought out to three slip s. The front bracket is slightly modified to make room for these rings on the inside. starting duty sufficient resistance is supplied to reduce the starting current when the notor to 1¼ times the normal full load current. In the running position the resist- is all cut out of the circuit. For speed regulation sufficient resistance is supplied to e the speed 50% on normal full load torque.

FIGS. 1,801 to 1,828.—Disassembled view of Western Electric three phase external resistance or slip ring mill type induction motor. It is adapted to severe working conditions, such as are met with in steel mills, crane and hoist service, etc. Designed for 220 or 440 volt, 25 cycle circuits. The frame is divided horizontally into an upper and a lower steel casting, both of which are bolted together at the corners by four heavy bolts. The lower casting is provided with four feet for bolting the motor to its foundation. The end of the upper frame which covers the slip rings is equipped with malleable iron covers held in place by lock bolts. The field and armature are of the usual construction. One end of the armature winding is protected against mechanical injury by the slip rings which are of heavy construction and of practically the same diameter as the armature, and the other end by a detachable flange of the same diameter as the outside of the winding. The slip rings are mounted on the same spider as the armature, so that the shaft can be removed without disturbing any of the connections. The brushes are equipped with riveted pigtails, and held in brass brush boxes machined to gauge. Heavy coiled clock springs are used to maintain an even pressure of the brushes on the slip rings. The armature leads are brought out through holes in the upper half of the frame, and the field leads are brought through a block, which fits in an opening in the upper edge of the lower half.

being enlarged by the growing practice of central stations generating polyphase current, of supplying their lighting service through single phase distribution, and permitting the use of single phase motors of moderate capacity on the lighting circuit.

The simplicity of single phase systems in comparison with polyphase systems, makes them more desirable for small alternating current plants.

The disadvantage of single phase motors is that they are not self-starting.

A single phase motor consists essentially of an *armature and field magnet having a single phase winding and also some phase splitting arrangement for starting.*

FIG. 1829.—General Electric single phase induction motor. It is suitable for constant speed service where full load torque at starting does not exceed 140 per cent., and in general is adapted to drive all geared and belted machinery requiring *constant speed with light or moderate* starting torque.

FIG. 1,830.—Simplified diagram showing the principle of phase splitting for starting single phase induction motors. By the use of an auxiliary set of coils connected in parallel with the main coils and having in series a resistance or condenser as shown, the single phase current delivered by the alternator is "split" into two phases, which are [illegible] to produce a rotating field on which the motor is started.

Ques. Why is a single phase motor not self-starting?

Ans. Because the nature of the field produced by a sing phase current is oscillating and not rotating.

Ques. How is a single phase motor started?

Ans. By splitting the phase, a field is set up normal to t

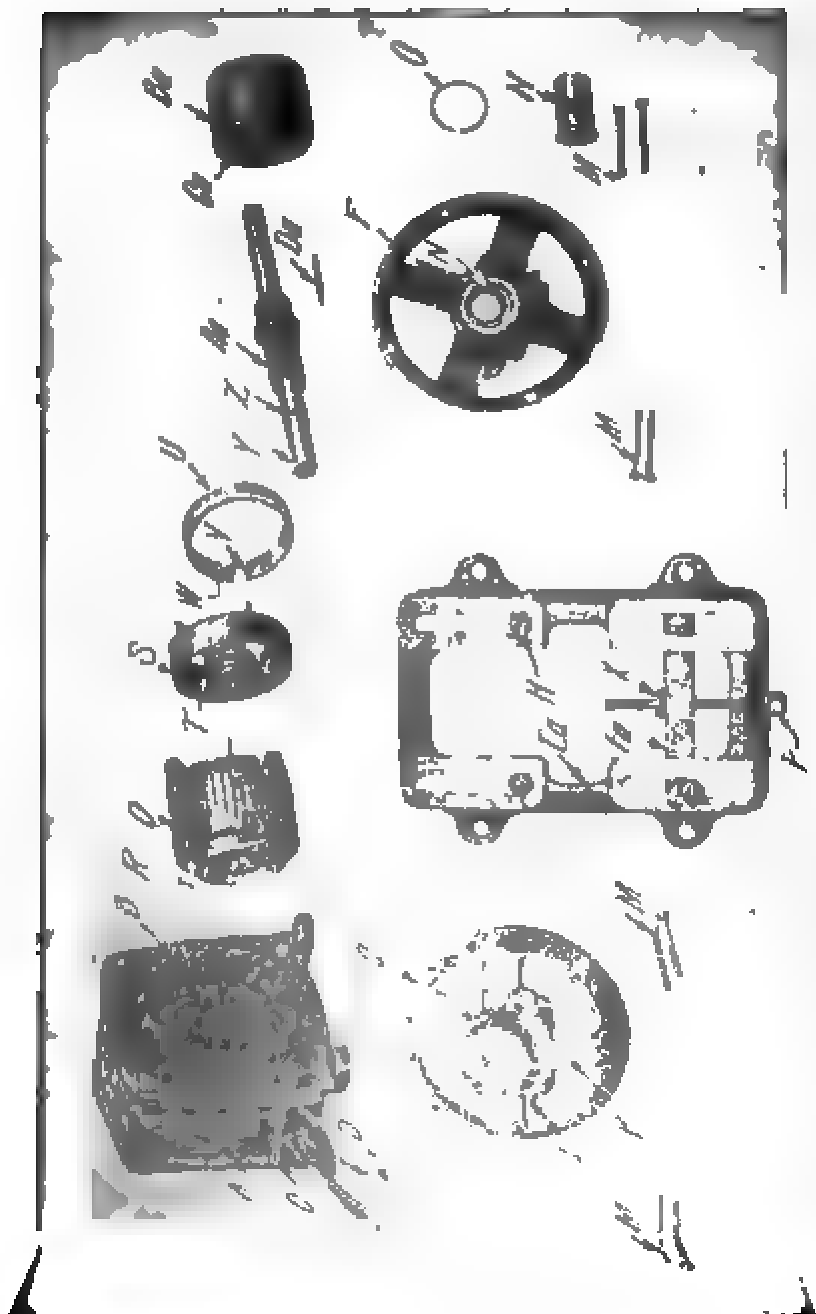
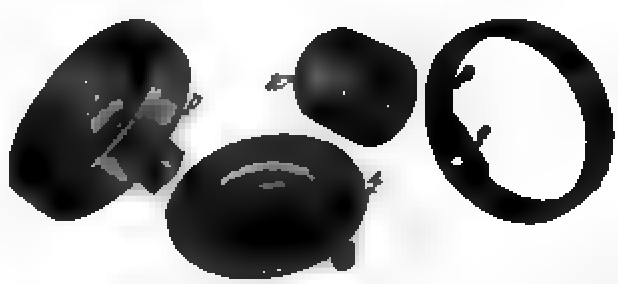


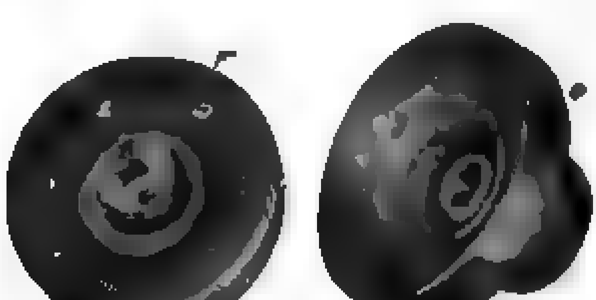
FIG. 1,849 to 1,850.—Parts of [illegible] single phase clutch type induction motor. The armature is of [illegible] squirrel cage type, the core laminæ being assembled upon a steel [illegible]. On starting the armature revolves *freely* around the shaft on roller bearings until it accelerates to about 75% of its rated speed when a centrifugal clutch engages with an outer shell keyed directly on the shaft thus throwing on the load. This type of motor is adapted to drive all belted, geared or direct connected machinery requiring constant speed with moderate starting torque, such as generators, blowers, line shafting in machine shops and factories, drill presses, laundry machinery, baking machinery, and the like. When greater torque is required at the moment of starting type RI motors should be used or clutch couplings may be installed between the motor and the machine it is to drive. The parts are as follows A, field frame; B, field coils; C, terminal block, D, terminal block screws, E, connectors, F, bearing head pulley end, G, bearing head opposite pulley end; H, motor clamping bolts, I, oil well cover, J, oil well plug; K, drain plug, L, oil filler; M, cap bolts; N, bearing lining, O, oil ring; P, belt tightener screw, Q, armature core; R latch, S, driving shell, T, driving shell set screw, U, clutch ring; V, clutch ring spring, W, spring adjusting screw X nut for belt tightener screw; [illegible]

axis of the armature, and nearly 90° displaced in phase from the field in that axis. This cross field produces the useful torque.

FIG. 1,851.—General Electric high resistance clutch type smooth core squirrel cage armature of single phase induction motor. The core laminæ are slotted near the circumference to retain the bar inductors, which extend beyond the core at either end where they are permanently connected to heavy short circuiting rings.



FIGS. 1,852 to 1,855.—Parts of General Electric centrifugal clutch pulley as used on clutch type, single phase induction motor. A, clutch; B, friction band; C, adjusting spring; D, outer clutch shell with pulley sleeve; E, solid removable pulley; P, internal mechanism comprising parts A, B, and C; G, outer shell and pulley comprising parts D and E.



FIGS. 1,856 and 1,857.—Partly assembled clutch pulley. P, internal mechanism comprising parts A, B, C, of fig. 1,852. G, outer shell and pulley, comprising parts D and E of fig. 1,852.

Phase Splitting; Production of Rotating Field from Oscillating Field.—As previously stated, an oscillating field, *that is, one due to a single phase current, does not furnish an starting torque.* It is therefore necessary to provide a rotat

field for a single phase induction motor to start on, which, af the motor has come up to speed, may be cut out and the mo will then operate with the oscillating field. . . . . .

A rotating field may be obtained from single phase current what is known as *splitting the phase.*

Fig. 1,858.—Switch end view of General Electric drawn shell type fractional horse po single phase motor.

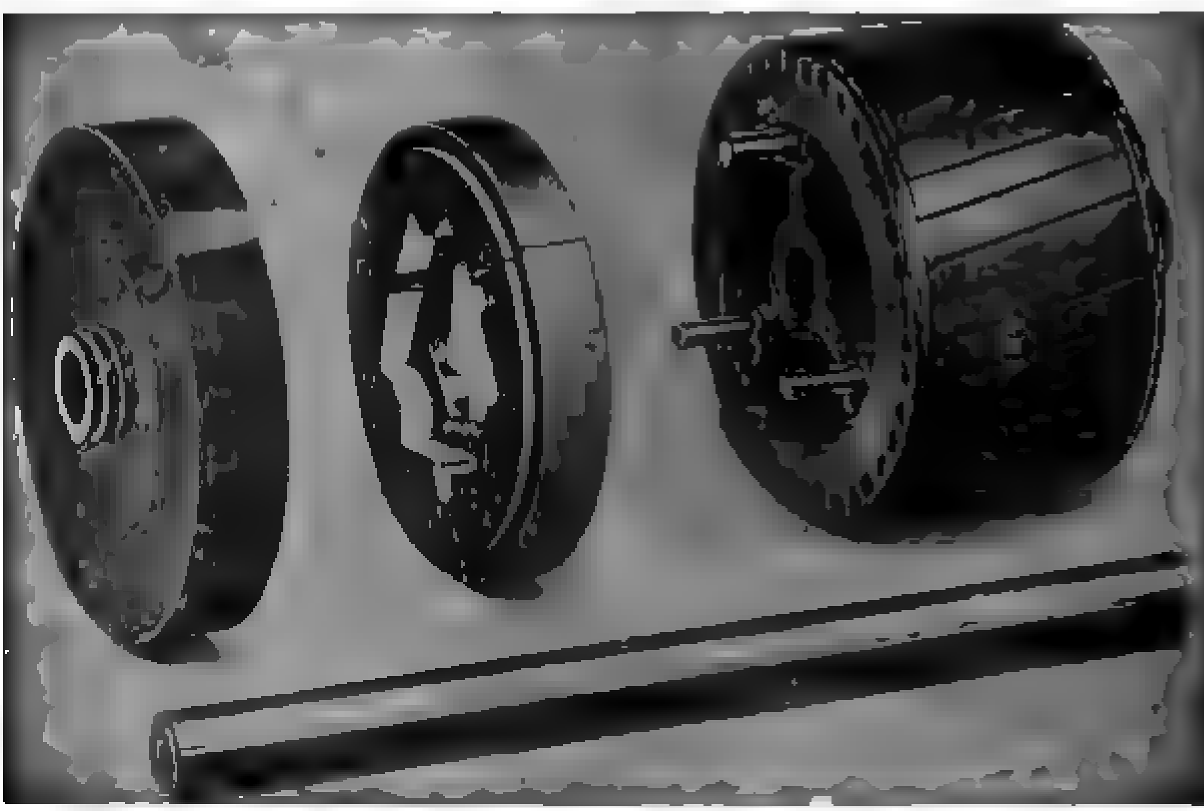
Ques. Describe one method of splitting the phase.

Ans. The field of the motor is provided, in addition to t main single phase winding, with an auxiliary single phase windir and the two windings are connected in parallel to the sin *phase supply* mains with a resistance or a condenser placed *series with* the single phase winding, as shown in diag *fig. 1.830,* the two windings being displaced from each

on the armature about 90 magnetic degrees, just as in the ordinary two phase motor.

Ques. What is the construction of the two windings?

Ans. The main coils are of more turns than the auxiliary, being spread over more surface, and are heavier because they are for constant use; whereas the auxiliary coils are used only while starting.



FIGS. 1,859 to 1,862. Detail construction of clutch parts of General Electric drawn shell type fractional horse power single phase motor. The starting switch, which is assembled within the motor frame, consists essentially of three parts, a rotating member mounted on the armature and provided with two spring controlled pivoted levers in contact with an insulated collector ring.

Ques. What are the auxiliary coils sometimes called?

Ans. *Starting coils.*

Ques. What are "shading" coils?

Ans. Auxiliary coils as placed on fan motors in the manne *shown in fig. 1,863.*

Ques. How can single phase motors be started without the use of external phase splitting devices?

Ans. Such apparatus may be avoided by having the auxiliary winding of larger self-inductance than the main winding.

Ques. What is the character of the starting torque produced by splitting the phase?

Ans. It does not give strong starting torque.

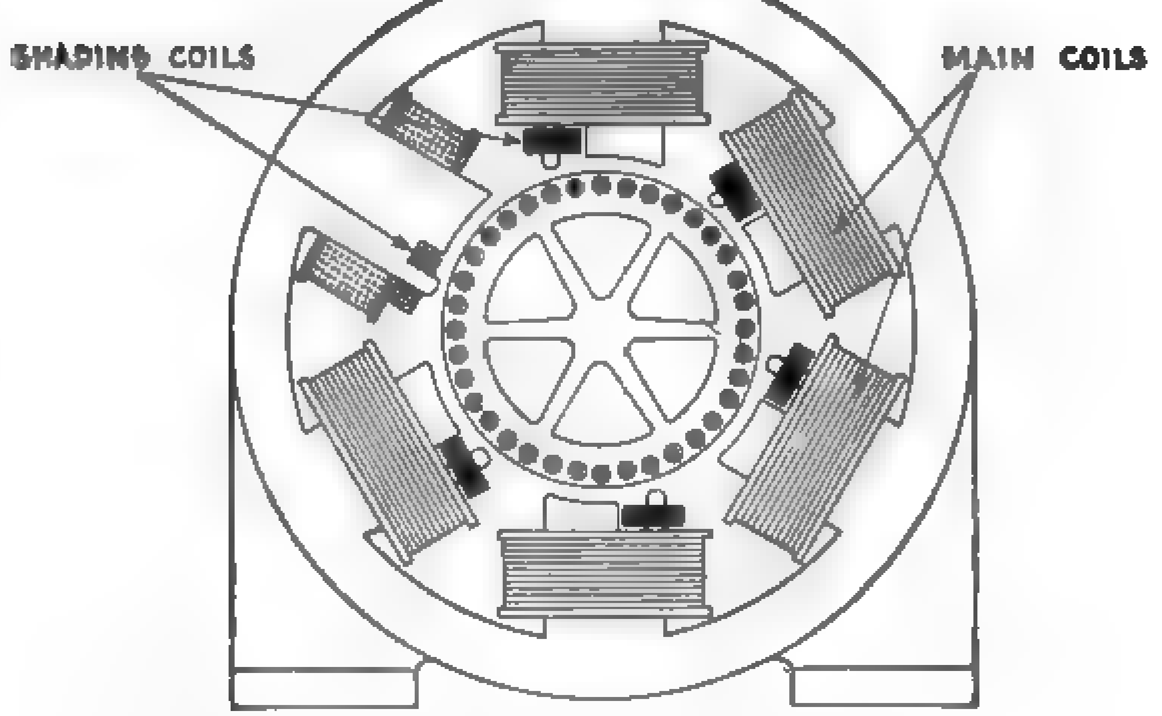


FIG. 1,863.—Single phase fan motor with *shading coils* for starting. In addition to the main field coils, one tip of each pole piece is surrounded by a short circuited coil of wire or frame of copper, as indicated in the figure. This coil, or copper frame, is called a *shading coil* and it causes a phase difference between the pulsating flux that emanates from the main portion of each polar projection and the pulsating flux which emanates from the pole tip, thus introducing a two phase action on the armature which is sufficiently pronounced to start the motor.

Ques. How is the plain squirrel cage armature modified to enable the motor to start with a heavier load?

Ans. An automatic clutch is provided which allows the *armature to turn free on the shaft until it accelerates almost to running speed.*

This type motor is known as the *clutch type* of single phase induction motor. In operation when the circuit is closed, the armature starts to revolve upon the shaft; when it reaches a premeditated speed, a centrifugal clutch expands and engages the clutch disc, which is fastened to the shaft.

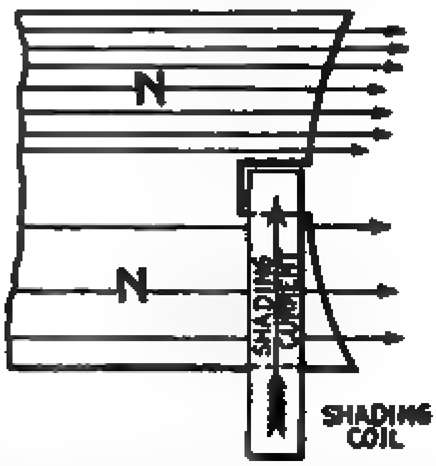
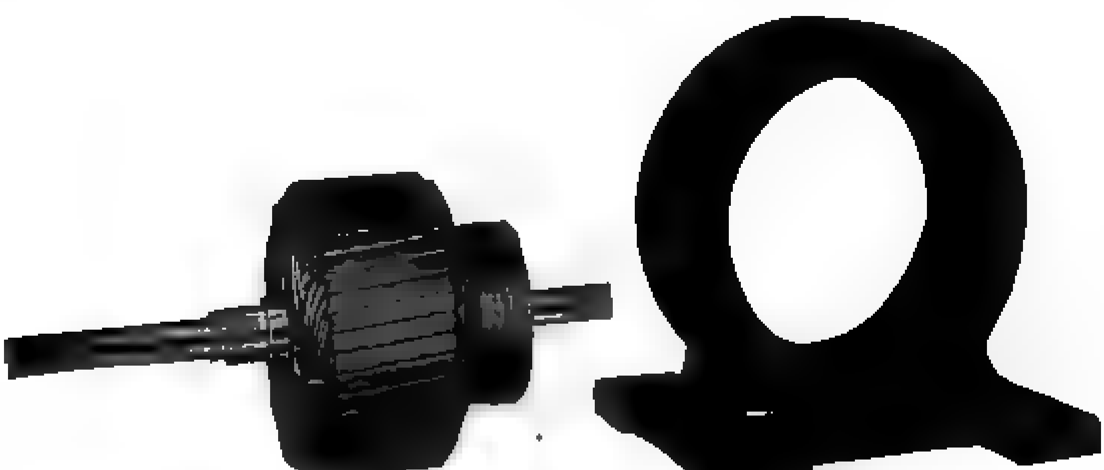


FIG. 1864.—Diagram showing action of shading coil in alternating current motor. The extremities of these pole pieces are divided into two branches, one of which a copper ring called a *shading coil* is placed as shown, while the other is left *unshaded*. The action of the shading coils is as follows: Consider the field poles to be energised by single phase current, and assume the current to be flowing in a direction to make a north pole at the top. Consider the poles to be just at the point of forming. Lines of force will tend to pass downward through the shading coil and the remainder of the pole. Any change of lines within the shading coil generates an e. m. f., which causes to flow through the coil a current of a value depending on the e. m. f. and always in a direction to oppose the change of lines. The field flux is, therefore, partly shifted to the free portion of the pole, while the accumulation of lines through the shading coil is retarded.



FIGS. 1,865 and 1,866.—Fort Wayne split phase factional horse power induction motor with stationary armature. The object of placing the squirrel cage armature winding on the stationary part or frame is to decrease the radial depth of the latter more than would be *possible with the usual arrangement* where the armature forms the rotating part. The *small radial depth of the stationary armature* makes possible a revolving field of maximum *diameter giving in turn an* exceptionally large air gap area, which reduces the magnet*ing current, hence improves* the power factor of the motor.

Ques. Explain in detail the action of the clutch type motor in starting.

Ans. It can start a load which requires much more than f load torque at starting, because the motor being nearly up full speed, has available not only its maximum overload capaci but also the momentum of the armature to overcome the iner of the driven apparatus. In this it is assisted by a certain amou of slippage in the clutch, which is the case when the armatu speed is pulled down to such a point as to reduce the grip of t centrifugal clutch.

FIGS. 1,867 and 1,868.—General Electric dissembled clutch as used on clutch type, single ph (KS) induction motor. In starting, the armature revolves freely on the shaft until appro mately 75 per cent. of normal rated speed is reached. The load is then picked up by automatic action of a centrifugal clutch, which rigidly engages an outer shell, ke directly to the shaft. The brass friction band of the clutch is permanently keyed to pulley end of the armature.

Commutator Motors.—Machines of this class are simil in general construction to direct current motors. They have closed coil winding, which is connected to a commutator.

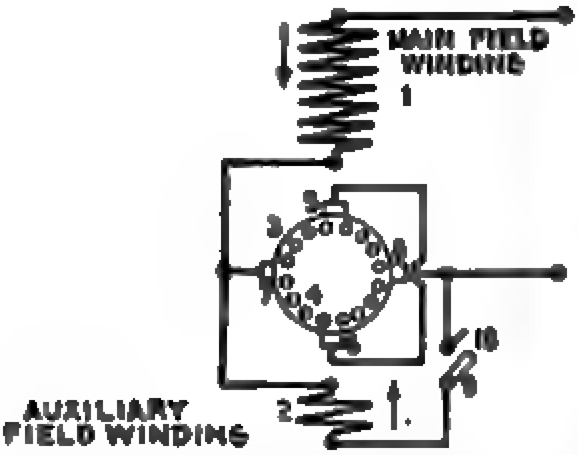
There are several types of commutator motor, namely:

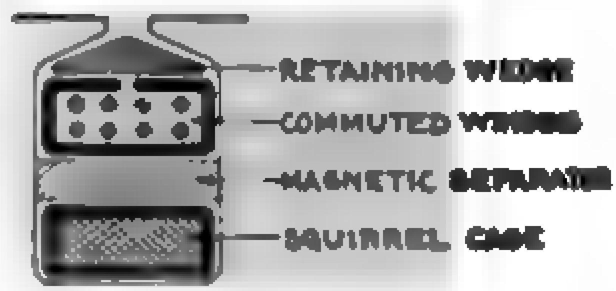
1. Series;
2. Shunt;
3. *Compensated;*
4. *Repulsion.*

Since, as stated, commutator motors are similar to direct current motors, the question may be asked: Is it possible to run a direct current motor with alternating current? If the mains leading to a direct current motor be reversed, the direction or rotation remains the same, because the currents through both the field magnets and armature are reversed. It must follow then that an alternating current applied to a direct current motor would cause rotation of the armature.

FIG. 1,869.—Wagner single phase variable speed commutator motor. The commutator is of the regular horizontal type and the brushes remain in contact all the time. As the torque of alternating motors varies directly as the square of the applied pressure, wide speed variation may be obtained by varying the voltage applied at the motor terminals.

Action of Closed Coil Rotating in Alternating Field.—When a closed coil rotates in an alternating field, there are several *different pressures set* up and in order to carefully distinguish *between them, they* may be called:





FIGS. 1,870 and 1,871.—Diagrams illustrating construction and operation of Wagner "unity power factor" single phase motor. In the field construction, fig. 1,870, two windings are used. The main winding 1 produces the initial field magnetization as heretofore; the auxiliary winding 2 controls the power factor or "compensates" the motor. The main structural departure is in the armature, the construction of which is more clearly indicated in fig. 1,871. Here again two windings are employed. The main or principal winding 4 is of the usual well known squirrel cage type and occupies the bottom of the armature slots. The second or auxiliary winding 3 is of the usual commuted type, is connected to a standard form of horizontal commutator and occupies the upper portion of the armature slots. Between the two is placed a magnetic separator in the form of a rolled steel bar. Two sets of brushes are provided, as indicated in the diagram of connections shown in fig. 1,870. The main pair of brushes 5-6 is placed in the axis of the main field winding 1 and is short circuited. The auxiliary pair of brushes 7-8 is placed at right angles to the axis of the main field winding and is connected in series with it at starting. The auxiliary field winding 2 is permanently connected to one auxiliary brush 7, and is adapted to be connected to the other auxiliary brush 8 by means of the switch 9. The purpose of the peculiar armature construction illustrated in fig. 1,871 and of the brush arrangement and connections shown in fig. 1,870 is to accentuate, at starting, the effect of the squirrel cage along the axis 5-6 of the main field winding 1, while suppressing it as far as possible along the axis 7-8 at right angles to main winding. The magnetic separator placed above the squirrel cage winding 4 tends to suppress the effect of that winding along all axes, by making it less responsive to outside inductive effects. But the influence of the separator is nullified along the axis of the main field winding by the presence of the short circuited brushes 5-6, while no means are provided for nullifying its effects along the axis at right angles to that of the main field winding. Thus the main field winding 1 will be able to induce heavy currents in both armature windings because of the short circuited brushes in the axis 5-6, and in spite of the magnetic separator, while the armature winding 3, connected in series with 1, will not be able to produce heavy currents in the squirrel cage winding 4 along the axis 7-8 because of the magnetic separator between 3 and 4, which shunts or side tracks the inducing magnetic flux. In operation, at starting, switch 9 of fig. 1,870 is open, the commuted winding 3 along the axis 7-8 being connected in series with the main field winding 1 and across the mains. The winding 1 induces a large current in the armature windings 3 and 4 along the axis 5-6, and the winding 3 produces a large flux along the axis 7-8. The armature currents in the main axis co-acting with the flux threading the armature along the auxiliary axis yield the greater part of the starting torque. As the motor speeds up, the squirrel cage gradually assumes those functions which it performs in the ordinary single phase, squirrel cage motor, developing a magnetic field of its own along the axis 7-8 and a correspondingly powerful torque which increases very rapidly as synchronism is approached but falls suddenly to zero at or near actual synchronism. It is known that the magnetizing currents circulating in the bars of the squirrel cage of a single phase motor have, at synchronism, double the frequency of the stator currents, the fluxes they produce must therefore also be of double frequency. Now, the magnetic separator is made of solid steel, and, while this separator forms a sufficiently effective shunt for the fluxes of line frequency induced from the field, it is quite ineffective as a shunt for the double frequency fluxes produced by the armature. With respect to the squirrel cage, the effect of this magnetic separator diminishes with increasing speed, and at synchronism the machine operates practically in the same manner as if the magnetic separator did not exist.

1. The transformer pressure;
2. The generated pressure;
3. The self-induction pressure.

These pressures may be defined as follows:

The transformer pressure ***is that pressure induced in the armature by the alternating flux from the field magnets.***

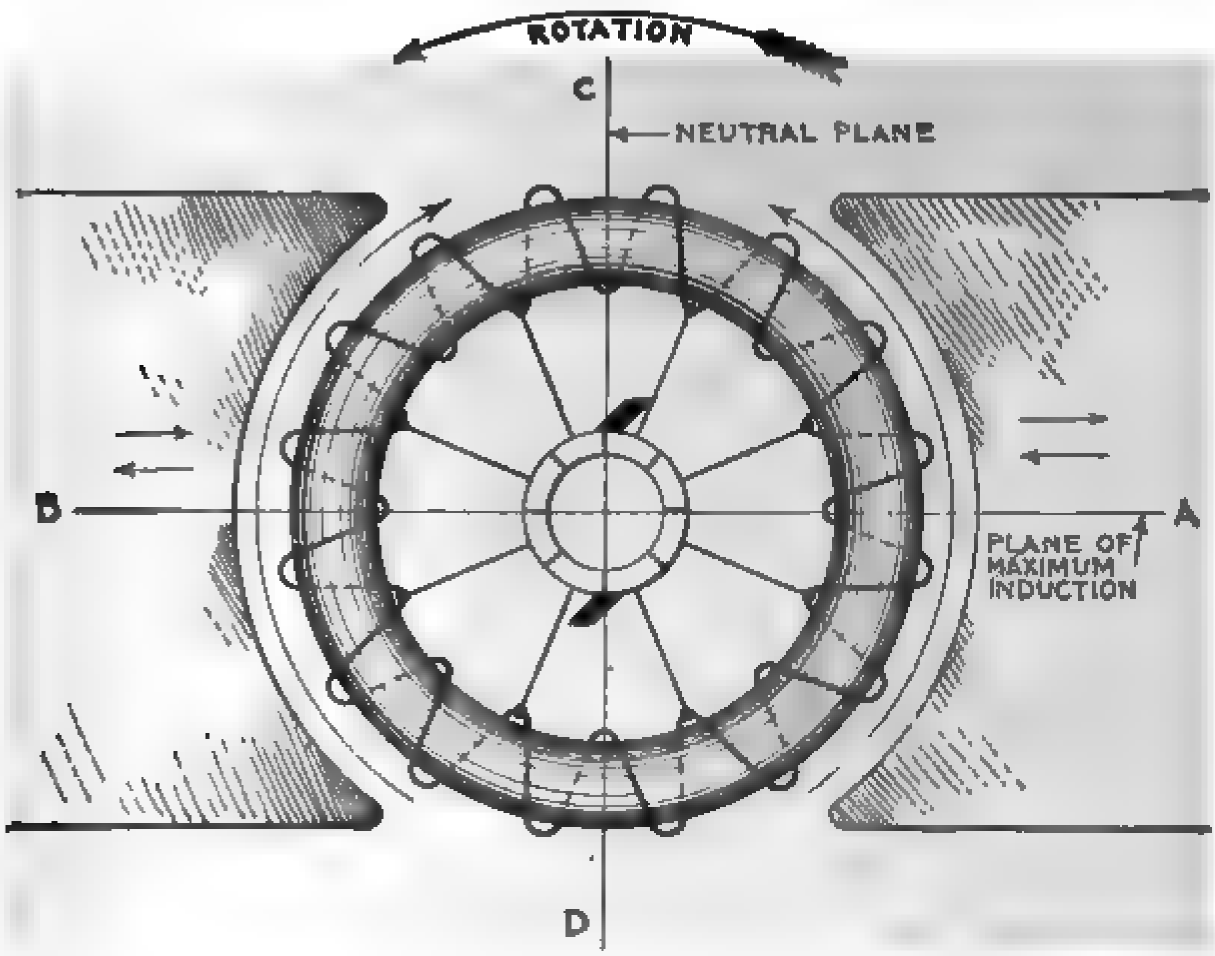


FIG. 1,872.—Diagram of ring armature in alternating field illustrating the principles of commutator motors.

For instance, assuming in fig. 1,872 the armature to be at rest, as the alternating current which energizes the magnets rises and falls in value, the variations of flux which threads through the coils of the ring winding, induce pressure in them in just the same way that pressure is induced in the secondary of a transformer.

A ring winding is used for simplicity; the same conditions obtain *in a drum winding.*

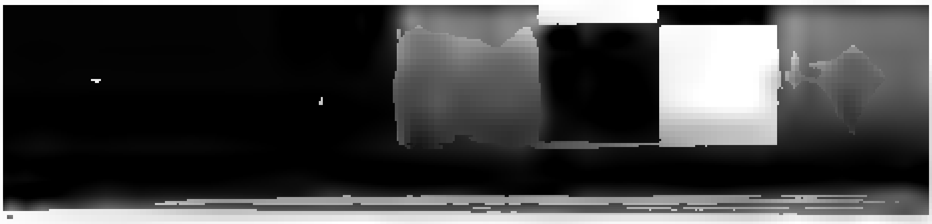
The generated pressure is that pressure ***induced in the armature by the cutting of the flux when the armature rotates.***

The self-induction pressure *is that pressure induced in both the field and armature by self-induction.*

Nature of the Generated Pressure.—In fig. 1,872, the generated pressure induced by the rotation of the armature is minimum at the neutral plane C D and maximum at A B. It tends to cause current to flow up each half of the armature from D to C, producing poles at these points.

FIG. 1,873.—Wagner single phase repulsion induction commutator motor. Its working principle is *repulsion start and induction operation*. Starting with the machine at rest, brushes in pairs cross connected through a low resistance conductor, bear upon the commutator, temporarily short circuiting the armature winding then developing a strong starting torque on the repulsion principle. On attaining full load speed the individual segments of the commutator are all positively connected together by the operation of an automatic centrifugal governor, thereby transforming the armature winding to the squirrel cage form, the motor then continuing as an induction motor. The governor at the same time removes the brushes from contact with the commutator to save wear. If the power service should fail for any reason, the motor returns to the starting condition, and picks up its load when the power comes on again without attention of the operator.

Nature of the Transformer Pressure.—This is caused by variations of the flux passing through each coil of the armature winding. Evidently this variation is least at the plane A B because at this point



the coils are inclined very acutely to the flux, and greatest at the plane C D where the coils are perpendicular to the flux. Accordingly, the transformer pressure induced in the armature winding is least at A B and greatest at C D.

The transformer pressure acts in the same direction as the generated pressure as indicated by the long arrows and gives rise to what may be called *local armature currents.*

Figs. 1,874 and 1,875.—Armature of Wagner single phase repulsion-induction commutator motor as seen from the commutator and rear ends, showing the vertical commutator and type of governor employed on the smaller sizes. The operation is explained in fig. 1,873.

Nature of the Self-Induction Pressure.—The self-induction pressure, being opposite in direction to the impressed pressure, it must be evident that in the operation of an alternating current commutator motor, the impressed pressure must overcome not only the generated

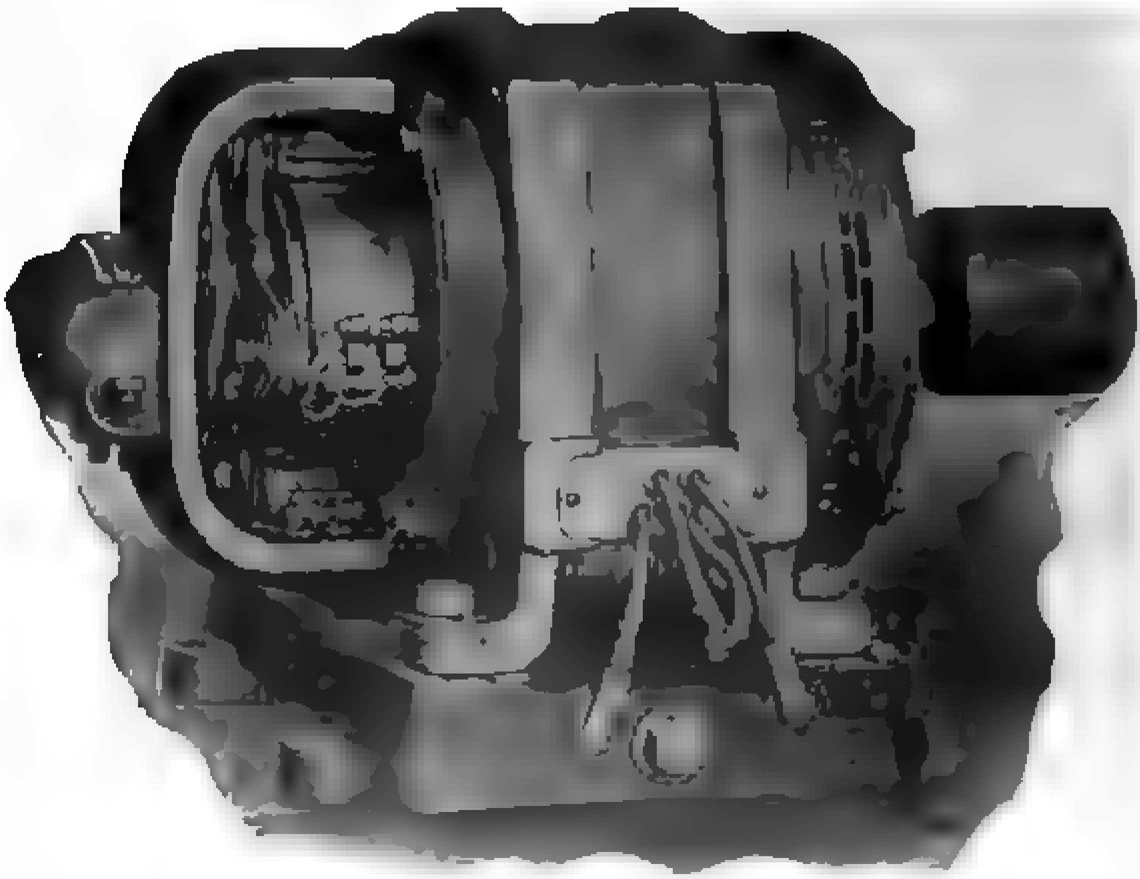


FIG. 1,870.—General Electric single phase compensated repulsion motor. The frame is of the riveted form and the field winding consists of distributed concentric coils, each being separately insulated and taped up before entering slot. The compensating winding (depending usually on the size of frame) forms either the center portion of the main winding or a separate winding concentric therewith. The polar groupings are arranged for a frequency of 25 and 60. There are four terminal leads permitting interchangeability of operation on 110 or 220 volt circuits. By connecting adjacent pairs of these terminals in multiple, motors of this type are made adaptable for 110 volt service, for double this pressure the four leading in wires are connected in series. The motor will operate satisfactorily where the arithmetical sum of voltage and frequency variation does not exceed 10 per cent., that is, the voltage may be 10 per cent. high if the frequency remain at normal, or the frequency may be 10 per cent. high assuming no variation in voltage. A decrease of 5 per cent. in frequency accompanied by a similar increase in voltage is permissible or, as above stated, any similar combination whose arithmetical sum is within 10 per cent. of normal. The armature winding is of the series drum type connected to a commutator carrying two sets of brushes, each set being displaced electrically from the other by 90 degrees. The first set, known as the **energy brushes**, is permanently short circuited and disposed at an angle to the lines of field or primary magnetization, as in an ordinary repulsion motor. The second set, or **compensating brushes**, is connected to a small portion of the primary winding included in the field circuit, so as to impress upon the armature an electromotive force which serves both to raise the power factor and at the same time maintain approximately synchronous speed at all loads. The armature laminations are built up on a cast iron sleeve having the same inside bore as the commutator. In case the shaft become damaged or worn, it can be readily pressed out and replaced without disturbing the commutator or windings. The motor is connected to run counter clockwise. Clockwise rotation is obtained by interchanging the leads to the compensating brushes and slightly shifting the brush holder yoke. This type motor may be thrown on the line without the use of a rheostat, and is suitable for operating refrigerating machines, air compressors, house pumps or similar apparatus where a float switch or pressure regulator is used to close or open the supply circuit.

pressure but also the self-induction pressure. Hence, as compared to an equivalent direct current motor, the applied voltage must be greater than in the direct current machine, to produce an equal current.

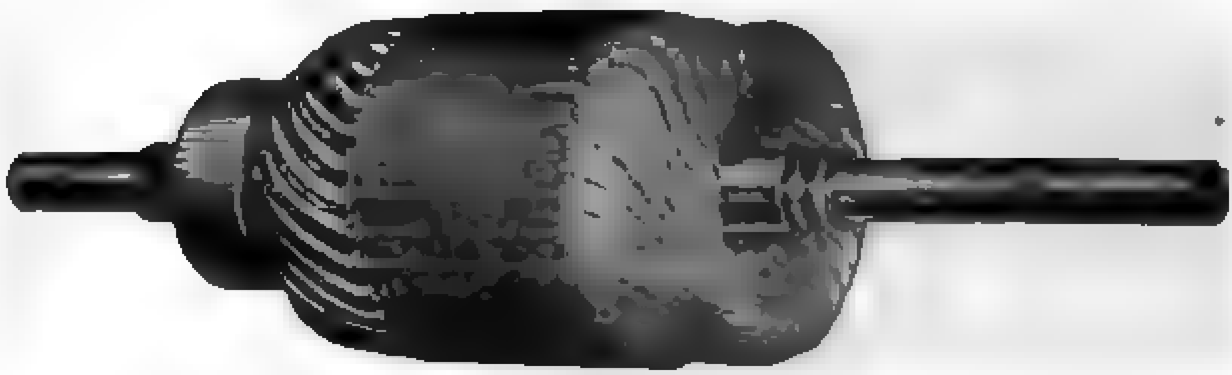


FIG. 1,877.—Armature of General Electric single phase compensated repulsion motor, assembled ready for dip and banding

FIG. 1,878.—Cast brush rigging of General Electric single phase compensated repulsion motor as used for the 3 and 5 horse power motors.

The Local Armature Currents.—These currents produced by the transformer pressure occur in those coils undergoing commutation. They are large, because the maximum transformer action occurs in them, that is, in the coils short circuited by the brushes.

Ques. Why do the local armature currents sparking?

Ans. Because of the sudden interruption of the large v of current, and also because the flux set up by the local cu being in opposition to the field flux, tends to weaken th just when and where its greatest strength is required fo mutation.

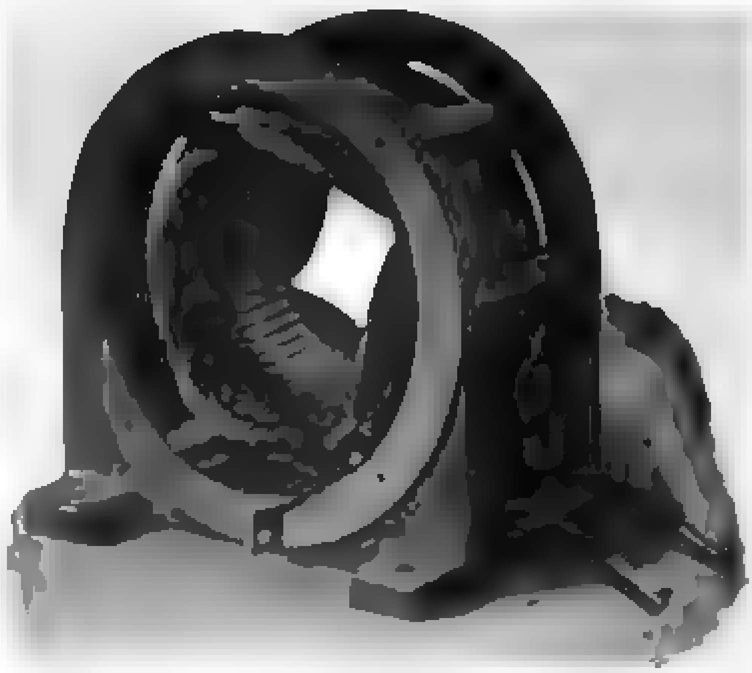


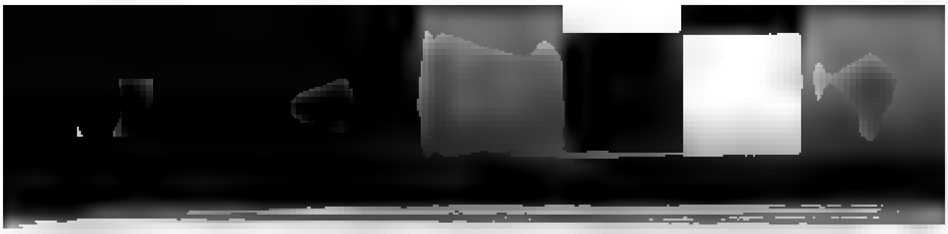
FIG. 1,679 -Field of Sprague single phase compensated repulsion motor. The fram skeleton form which exposes the core, giving effective heat radiation. The sin field winding is of the distributed concentric type. To facilitate connection to c either 110 or 220 volts, four plainly tagged leads are brought out to the back of the ble terminal board.

Ques. What is the strength of the local current?

Ans. They may be from 5 to 15 times the strength normal armature current.

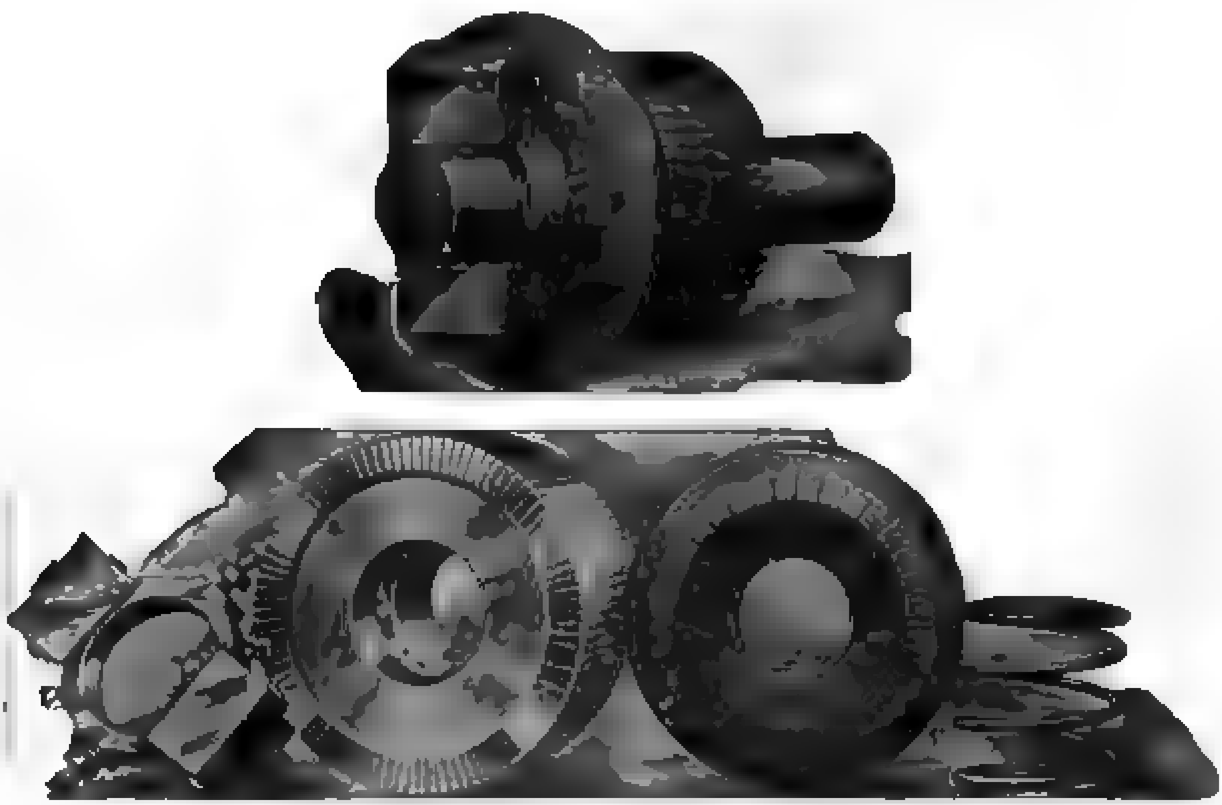
Ques. Upon what does the local armature cu *depend?*

Ans. Upon the number of turns of the short circuite *their resistance*, and the frequency.



Ques. How can the local currents be reduced to avoid heavy sparking?

Ans. 1. By reducing the number of turns of the short circuited coils, that is, providing a greater number of commutator bars; 2, reducing the frequency; and 3, increasing the resistance of the short circuited coil circuit: *a*, by means of high resistance connectors; or *b*, by using brushes of higher resistance.



FIGS. 1,880 to 1,884.—Assembly and disassembled view of short circuiting device as used on Bell single phase repulsion induction motor. The armature, which is wound in a similar manner to those used in direct current motors, has a commutator, and brushes, which being short circuited on themselves, allow great starting torque, with small starting current. The motor starts by the repulsion principle, and on reaching nearly full speed, a centrifugal governor pushes the copper ring against the commutator segments, thereby short circuiting them, and the motor then operates on the induction principle.

Ques. What are high resistance connectors?

Ans. The connectors between the armature winding and th *commutator bars*, as shown in fig. 1,885.

Ques. Does the added resistance of preventive leads, or high resistance brushes, materially reduce the efficiency of the machine?

Ans. Not to any great extent, because it is very small in comparison with the resistance of the whole armature winding.

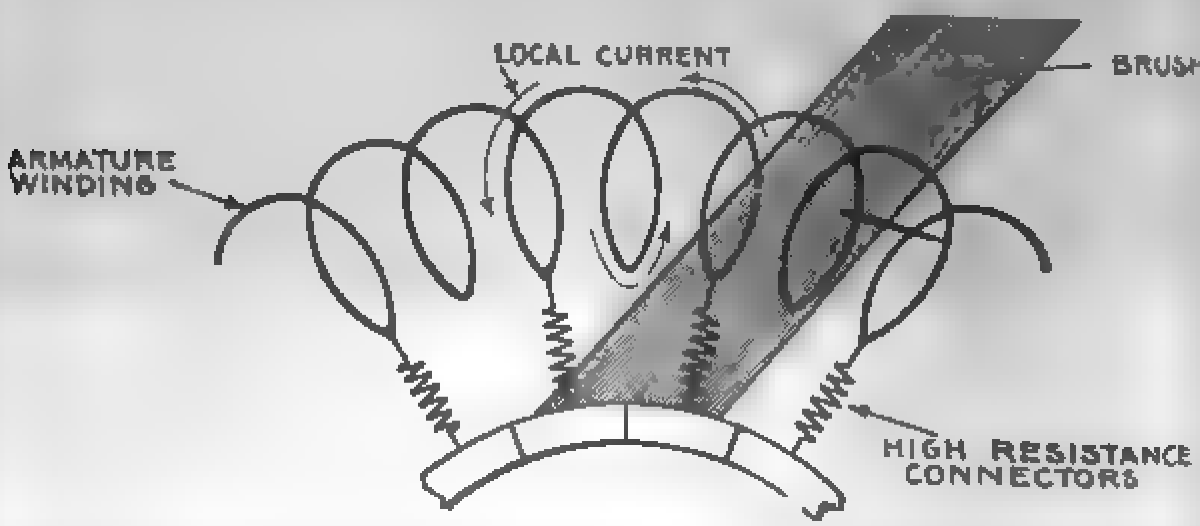


FIG. 1,885.—Section of ring armature of commutator motor showing local current set up by transformer action of the alternating flux.

Ques. What is the objection to reducing the number of turns of the short circuited coils to diminish the tendency to sparking?

Ans. The cost of the additional number of commutator bars and connectors as well as the added mechanism.

Ques. What effect has the inductance of the field and armature on the power factor?

Ans. It produces phase difference between the current and impressed pressure resulting in a low power factor.

Ques. What is the effect of this low power factor?

Ans. The regulation and efficiency of the system is impaired.

The frequency, the field flux and the number of turns in the winding *have influence* on the power factor.

Ques. How does the frequency affect the power factor?

Ans. Lowering the frequency tends to improve the power factor.

The use of very low frequencies has the disadvantage of departing from standard frequencies, and the probability that the greater cost of transformers and alternators would offset the gain.

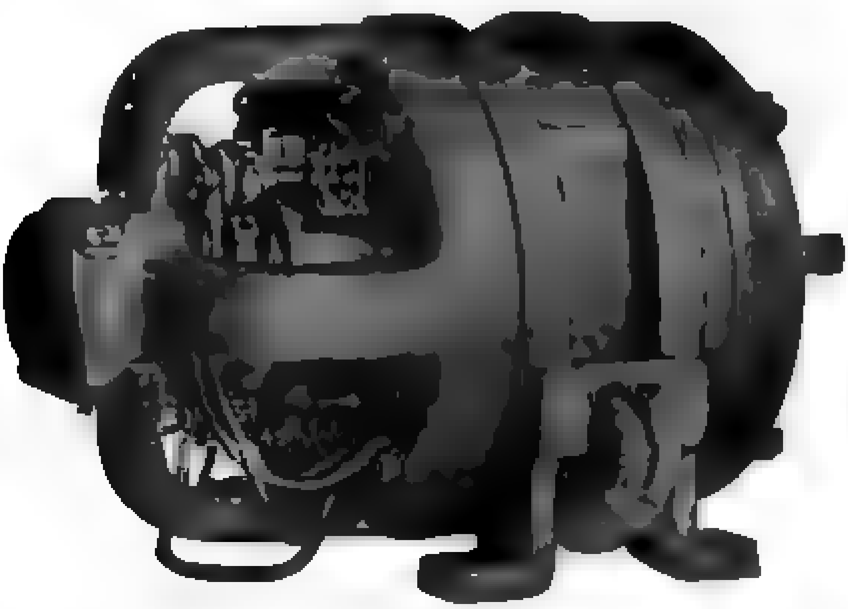


FIG. 1,886.—General Electric 5 H.P., 6 pole adjustable speed single phase compensated repulsion motor. This type is suitable for service requirements demanding the use of a motor whose speed can be adjusted over a considerable range, this speed at a fixed controller setting remaining practically unaffected by any load within the motor's rated capacity. With the controller on the high speed points, the motor possesses an inherent speed regulation between no load and full load of approximately 6 per cent. At the low speed points, under similar load conditions, the speed variation will be approximately 20 per cent. To secure adjustable speed control, the armature circuits employ transformers, whose primaries are excited by the line circuit. The secondaries of these transformers are divided into two sections; the first or "regulating" circuit is placed across the *energy* brushes; the other section, since it is connected in series with the compensating winding, maintains the high power factor and speed regulation obtained in the constant speed type. The speed range is 2 : 1, approximately one-half of this range being below and one-half above synchronous speed.

Series Motors.—This class of commutator motor is about the simplest of the several types belonging to this division. In general design the series motor is identical with the series direct current motor, but all the iron of the magnetic circuit must be laminated and a *neutralizing winding* is often employed.

It will be readily understood that the torque is produced in *the same way as* in the direct current machine, when it

remembered that the direction of rotation of the direct current series motor is independent of the direction of the voltage applied.

At any moment the torque will be proportional to the product of the current and the flux which it is at that moment producing in the magnetic system, and the average torque will be the product of the average current and the average flux it produces, so that if the iron parts be unsaturated, as they must be if the iron losses

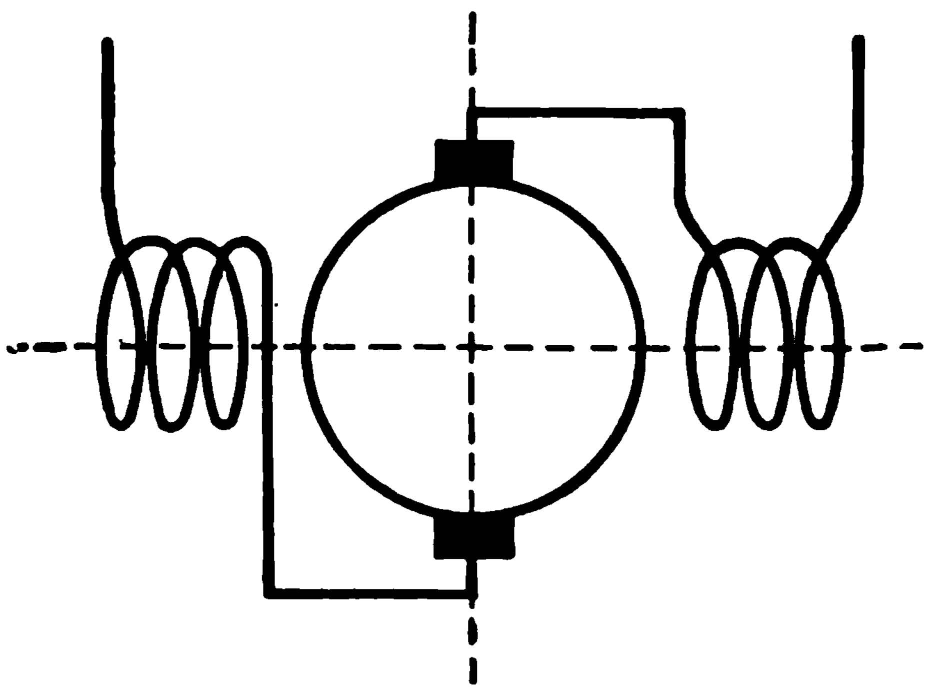


FIG. 1,887.—Diagram of single phase series commutator motor. It is practically the same as the series direct current motor, with the exception that all the metal of the magnetic circuit must be laminated.

are not to be too high, *the torque will be proportional simply to the square of the current*, there being no question of power factor entering into the consideration.

Ques. What are the characteristics of the series motor?

Ans. They are similar to the direct current series motor, the torque being a maximum at starting and decreasing as the speed increases.

Ques. For what service is the series motor especially suited?

Ans. On account of its powerful starting torque it is partic*ularly desirable* for traction service.

Neutralized Series Motor.—A chief defect of the series motor is the excessive self-induction of the armature, hence in almost every modern single phase series motor a neutralizing coil is employed *to diminish the armature self-induction.*

The neutralizing coil is wound upon the frame 90 magnetic degrees of half a pole pitch from the field winding and arranged to carry a current equal in magnetic pressure and opposite in phase to the current in the armature.

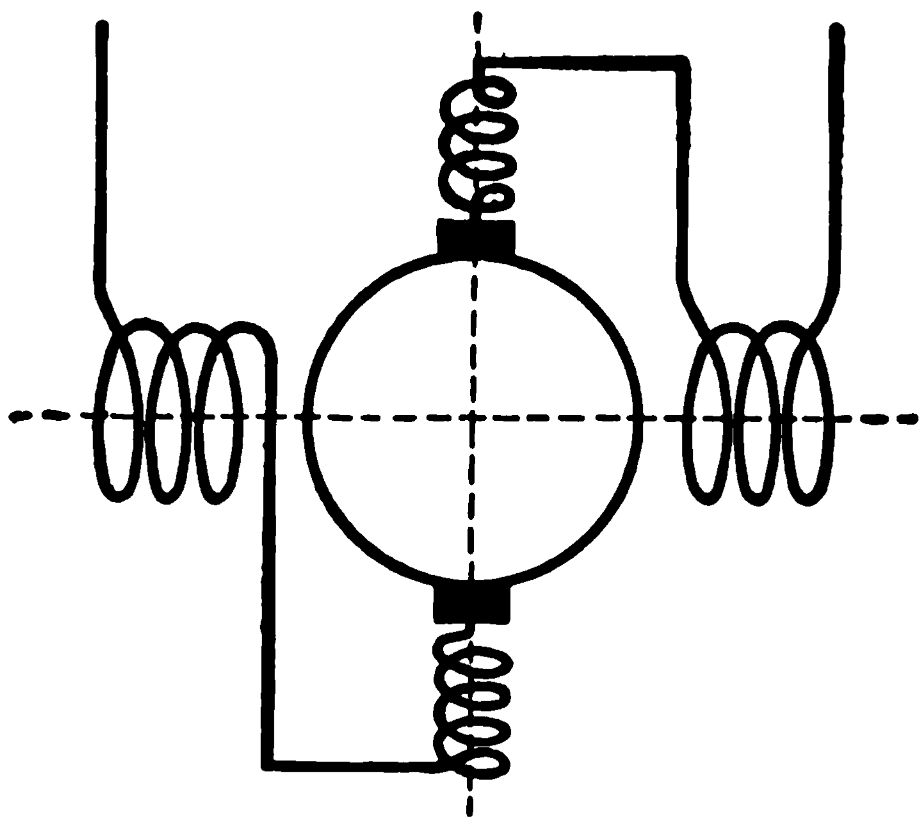


FIG. 1,888.—Diagram of neutralized series motor; **conductive method.** In the simple series motor, there will be a distortion of the flux as in the direct current motor. As the distorting magnetic pressure is in phase with that of the magnets, the distortion of the flux will be a fixed effect. If the poles be definite as in direct current machines, this distortion may not seriously affect the running of the motor, but with a magnetizing system like that universally adopted in induction motors the flux will be shifted as a whole in the direction of the distortion, which will produce the same effect as if in the former case the brushes had been shifted forward, whereas for good commutation they should have been shifted backward. As in direct current machines, this distortion is undesirable since it is not conducive to sparkless working, and also reduces to a more or less extent the torque exerted by the motor. The simplest remedy is to provide *neutralising coils* displaced 90 magnetic degrees to the main field coils as shown. The neutralizing current is obtained by the method of connecting the neutralizing coils in series in the main circuit.

The current through the neutralizing winding may be obtained, either

1. Conductively; or

2. Inductively.

...active method, fig. 1,888, the winding is connected in ...

...ctive method, fig. 1,889, the winding is short circuited ...d the current obtained inductively, the neutralizing ... virtually the secondary of a transformer, of which the ... primary.

...n is the conductive method to be preferred?

...n the motor is to be used on mixed circuits.

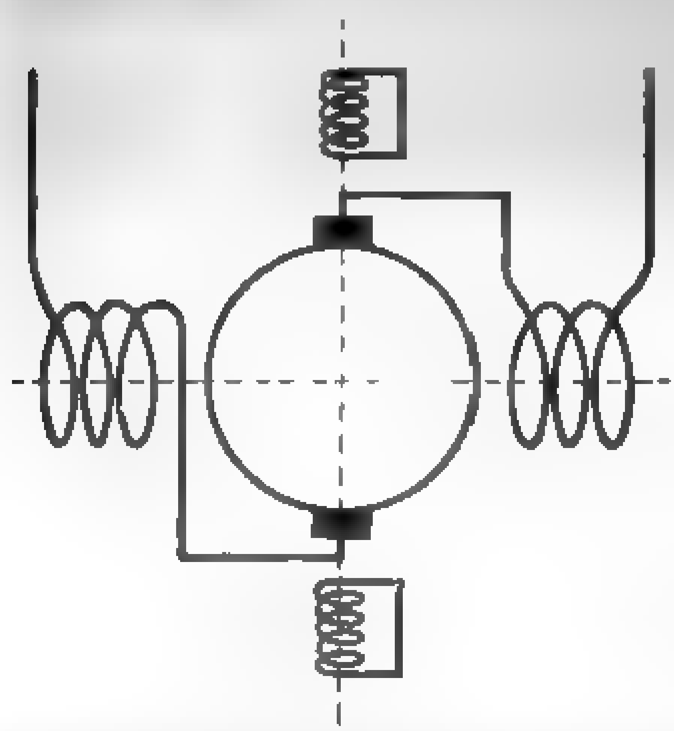
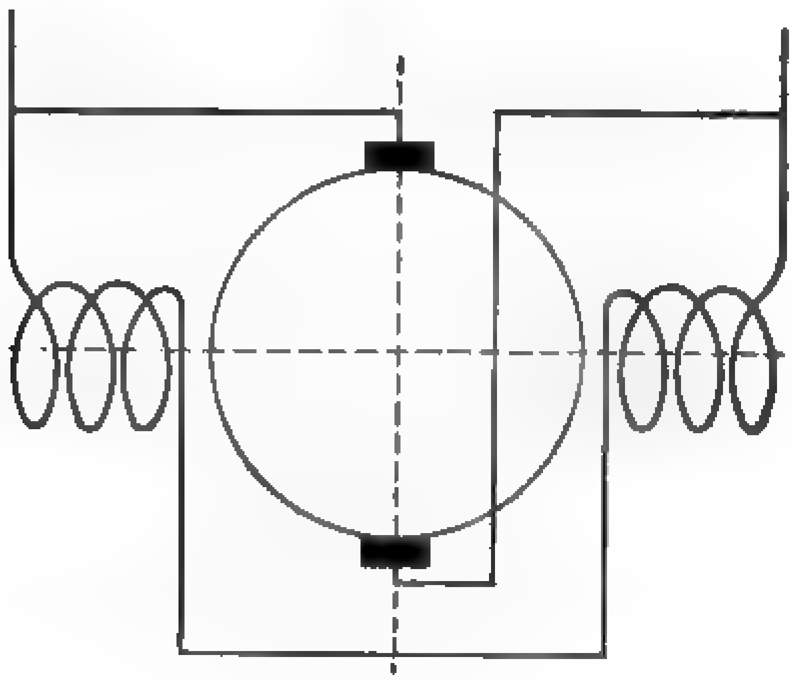
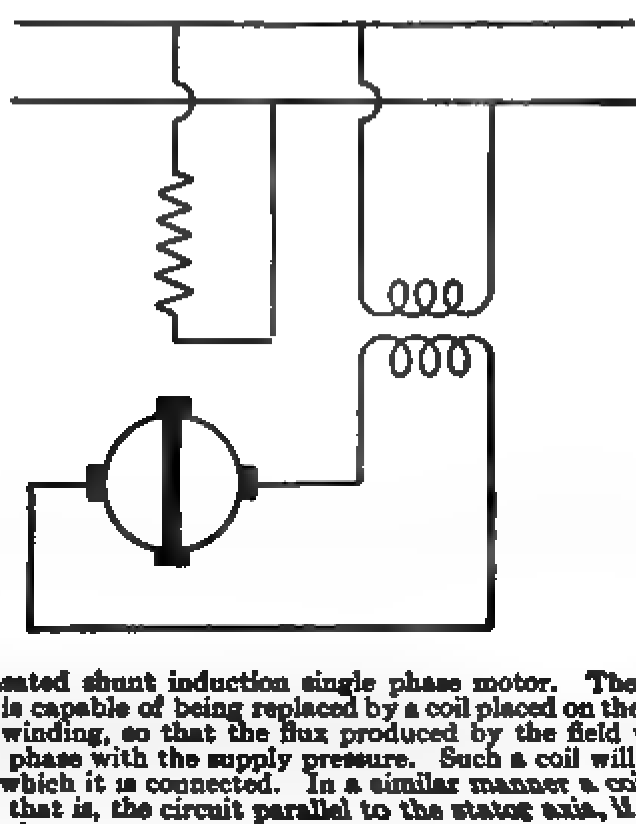


FIG. 1,889.—**Diagram of neutralized series motor; Inductive method. Although the conductive method** of neutralization is employed in nearly all machines, it is possible merely **to short circuit** the neutralizing winding upon itself instead of connecting it in series with **the armature circuit**. In this case the flux due to the armature circuit cannot be eliminated **altogether, as** sufficient flux must always remain to produce enough pressure to balance **that due to the** residual impedance of the neutralizing coil. It would be a mistake to infer, **however, that** on this account this method of neutralization is less effective than the conductive one, since the residual flux simply serves to transfer to the armature circuit a drop **in pressure** precisely equivalent to that due to the resistance and local self-induction of **the neutralizing** coil in the conductive method.

Shunt Motors.—The simple shunt motor has inherently many properties which render it unsuitable for practical use, and accordingly is of little importance. Owing to the many turns of the field winding there is large inductance in *the shunt field circuit.*



IG. 1,890.—Diagram of simple shunt commutator motor. Owing to its many inherent defects it is of little importance.



IG. 1,891.—Compensated shunt induction single phase motor. The transformer shown in the arrangement is capable of being replaced by a coil placed on the frame having the same axis as the field winding, so that the flux produced by the field winding induces in the coil a pressure in phase with the supply pressure. Such a coil will now be at right angles to the circuit to which it is connected. In a similar manner a coil at right angles to the armature circuit, that is, the circuit parallel to the stator axis, if connected in series with that circuit, *will also* serve to compensate the motor.

The inductance of the armature is small as compared with that of the field; accordingly, the two currents differ considerably in phase.

The phase difference between the field and armature currents and the corresponding relation between the respective fluxes results in a weak torque.

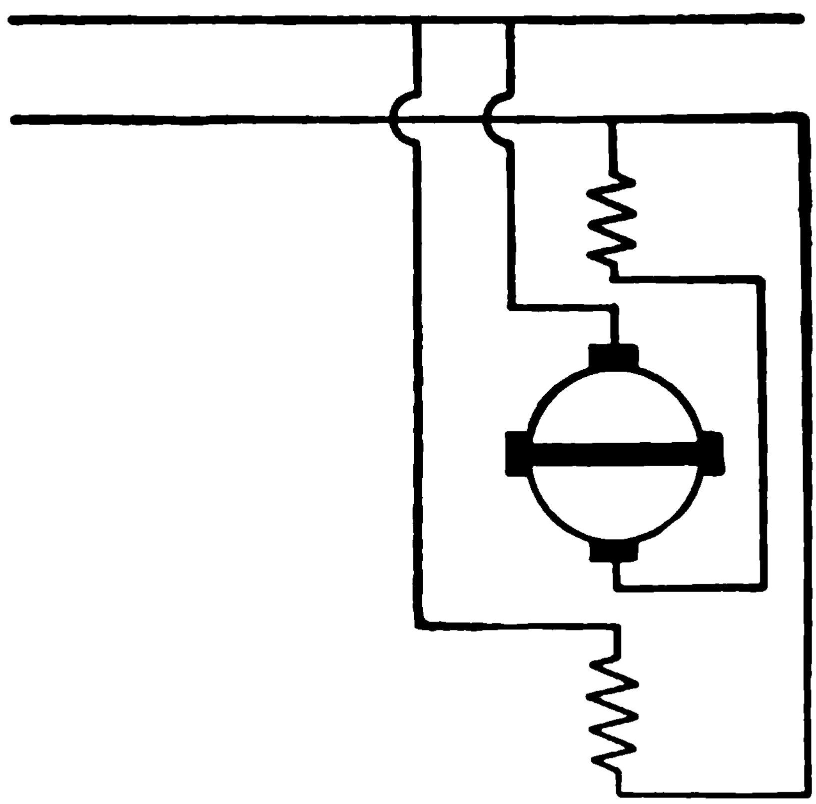


FIG. 1,892.—Fynn's shunt conductive single phase motor. In order to supply along the stator axis a constant field, suitable for producing the cross flux to which the torque is due by its action on the circuit perpendicular to the stator axis, the "armature circuit," as it may be called, has a neutralizing coil in series with it, so that the armature circuit and neutralizing coil together produce no flux. In addition to this, there is a magnetizing coil along the same axis, which is connected across the mains and so produces the same flux as the primary coil in a shunt induction machine. Fynn has proposed a number of methods of varying the speed and compensating this machine. It is, however, complicated in itself, and is only suited for very low voltages, so that on ordinary circuits it would need a separate transformer.

It is necessary to use laminated construction in the field circuit to avoid eddy currents, which otherwise would be excessive. Fig. 1,890 is a diagram of a simple shunt commutator motor.

Repulsion Motors.—In the course of his observations on the effects of alternating currents, in 1886-7, Elihu Thomson observed that a copper ring placed in an alternating magnetic field *tends either to* move out of the field, that is, it is repelled by the

field (hence the name **repulsion motor**), or to return so as to set itself edgeways to the magnetic lines.

The explanation of the repulsion phenomenon is as follows: When a closed coil is suspended in an alternating field so that lines of force pass through it, as in fig. 1,893, an alternating pressure will be induced in the coil which will be 90° later in phase than the inducing flux, and since every coil contains some in-

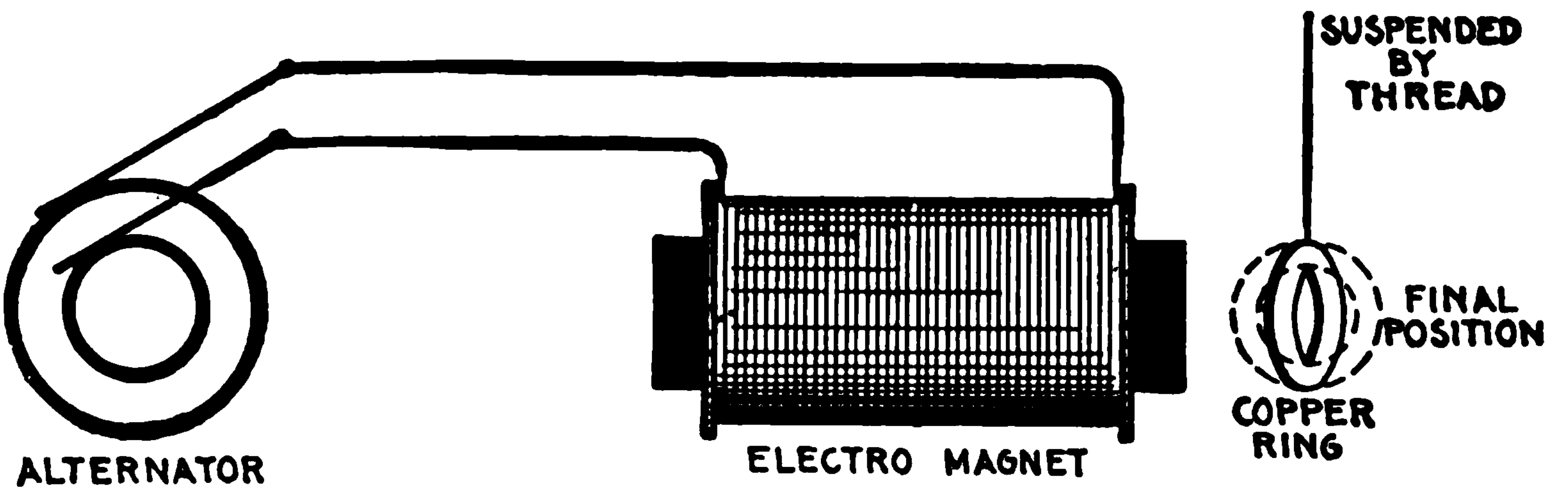
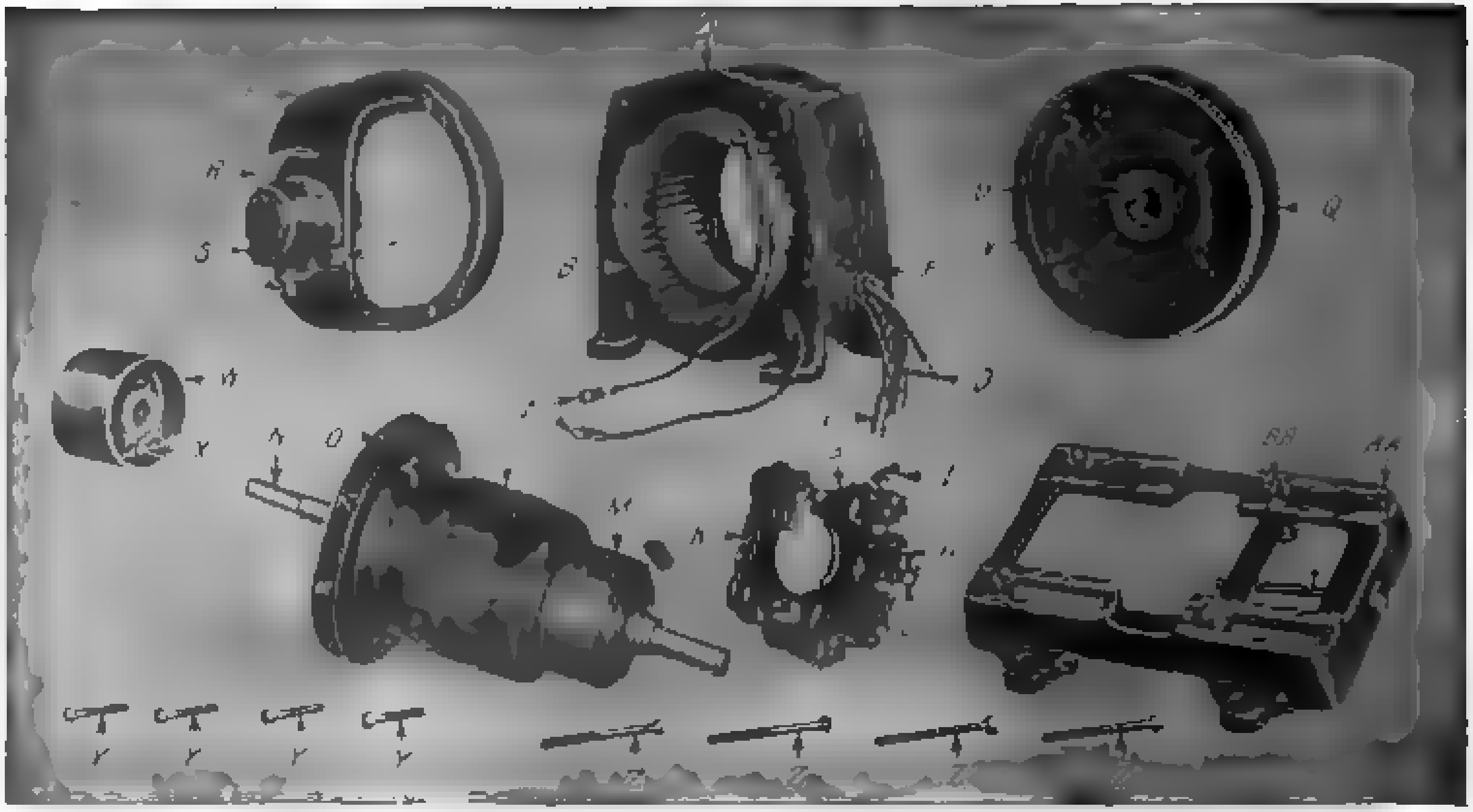


FIG. 1,893.—Effect of alternating field on copper ring. *If a copper ring be suspended in an alternating field so that the plane of the ring is oblique to the lines of force, it will turn until its plane is parallel to the lines of force,* that is, to the position in which it does not encircle any lines of force. The turning moment acting upon the ring is proportional to the current in it, to the strength of the field, and to the cosine of the angle β. Hence it is proportional to the product sin β cos β. The tendency to turn is zero both at 0° and at 90°; in the former case because there is no current, in the latter because the current has no leverage. It is a maximum when $\beta = 45°$. Even in this position there would be no torque if there were no lag of the currents in the ring, for the phase of the induced pressure is in quadrature with the phase state of the field. When the field is of maximum strength there is no pressure, and when the pressure reaches its maximum there is no field. If there be self-induction in the ring causing the current to lag, there will be a net turning moment tending to diminish β. The largest torque will be obtained when the lag of the current in the ring is 45°.

ductance the resulting current will lag more or less with respect to the pressure induced in the coil.

The cosine of this phase relation becomes a negative quantity which means that the coil is **repelled** by the field.

It is only when the ring is in an oblique position that it tends t
turn. If it be placed with its plane directly at right angles to t



FIGS. 1,894 to 1,908.—Parts of General Electric single phase compensated repulsion motor. The field frame employs the riveted form of construction, so that the ends of the laminations are exposed directly to the air, insuring low operating temperatures and high overload capacity. The field winding consists of a main winding of the distributed concentric type, and a compensating winding. The series type of winding is employed, and the completed rotor is treated with a special insulating compound, which renders the coils moisture proof under ordinary conditions. On motors of more than 2 horse power capacity a ventilating fan is attached to the rotor which provides a continuous supply of cool air while the motor is in operation. Two types of brush holder yoke are used. The smaller motors use a moulded yoke of insulating compound, reinforced by a cast iron L section ring embedded in the moulded structure. Cast iron yokes are used on larger motors. The brushes are of carbon with copper pigtails which carry all the current. The brushes in this machine remain permanently in contact with the commutator. The parts are. A, field; B, field winding; C, line terminal; D, tube terminal; E, compensating terminal; F, terminal board; G, brush yoke; H, brush holder; I, carbon brush; J, brush stud; K, short circuit connection; L, armature; M, commutator; N, shaft; O, fan; P, commutator end shield; Q, pulley end shield; R, oil well cover; S, oil plugs; T, oil gauge; U, bearing lining; V, oil ring; W, pulley; X, pulley set screw; Y, commutator end shield holding bolts; Z, pulley end shield holding bolts; AA, base; BB, float bolts; CC, belt tightener screw.

direction of the magnetic lines, it will not turn; if ever so little displaced to the right or left, it will turn until its plane is parallel to the lines.

The production of torque may be explained by saying that the current induced in the ring produces a cross field which being out of phase with, and inclined to the field impressed by the

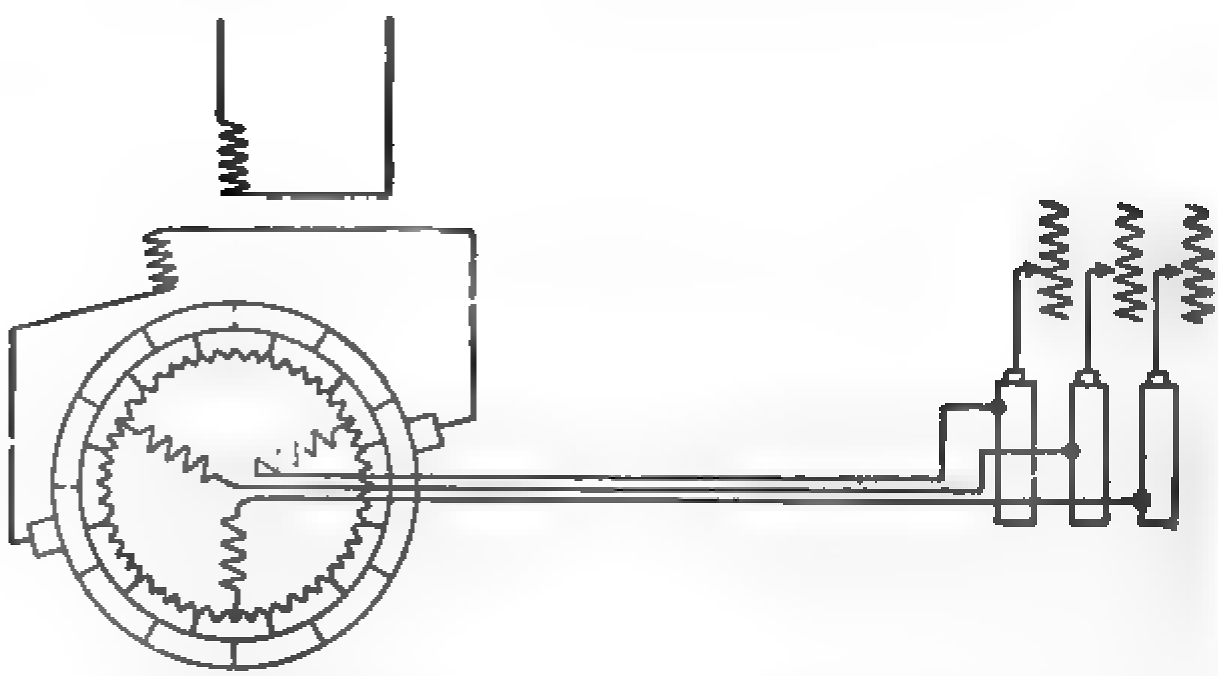


FIG. 1,909.—Fynn's compensated shunt induction motor. This is a combination of the compensated shunt induction motor with the ordinary squirrel cage form. In one form, in addition to the ordinary drum winding on the armature, there is another three phase winding into the "star," of which the drum winding is connected. This second winding is connected to three slip rings which are short circuited when the machine is up to speed. Upon the commutator are placed a pair of brushes connected to an auxiliary winding placed on the frame in such a position that the flux from the primary coil induces in it a pressure of suitable phase to produce compensation. The same pair of brushes is also used for starting.

primary alternating current, causes a rotary field, and this in turn, reacting on the conductor, a turning moment results.

Elihu Thompson took an ordinary direct current armature, placed it in an alternating field, and having short circuited the brushes, placed them in an oblique position with respect to the direction of the field. The effect was to cause the armature to rotate with a considerable torque.

The inductors of the armature acted just as an obliquely placed ring, but with this difference, that the obliquity was continuously preserved

and commutator, notwithstanding that the armature
us the rotation was continuous. This tendency of a
rn from an oblique position was thus utilized by him to
iculty of starting a single phase motor. With this object
constructed motors in which the use of commutator and
stricted to the work of merely starting the armature,
so started was then entirely short circuited on itself, though
d from the rest of the circuit, the operation then being solely
ction principle.

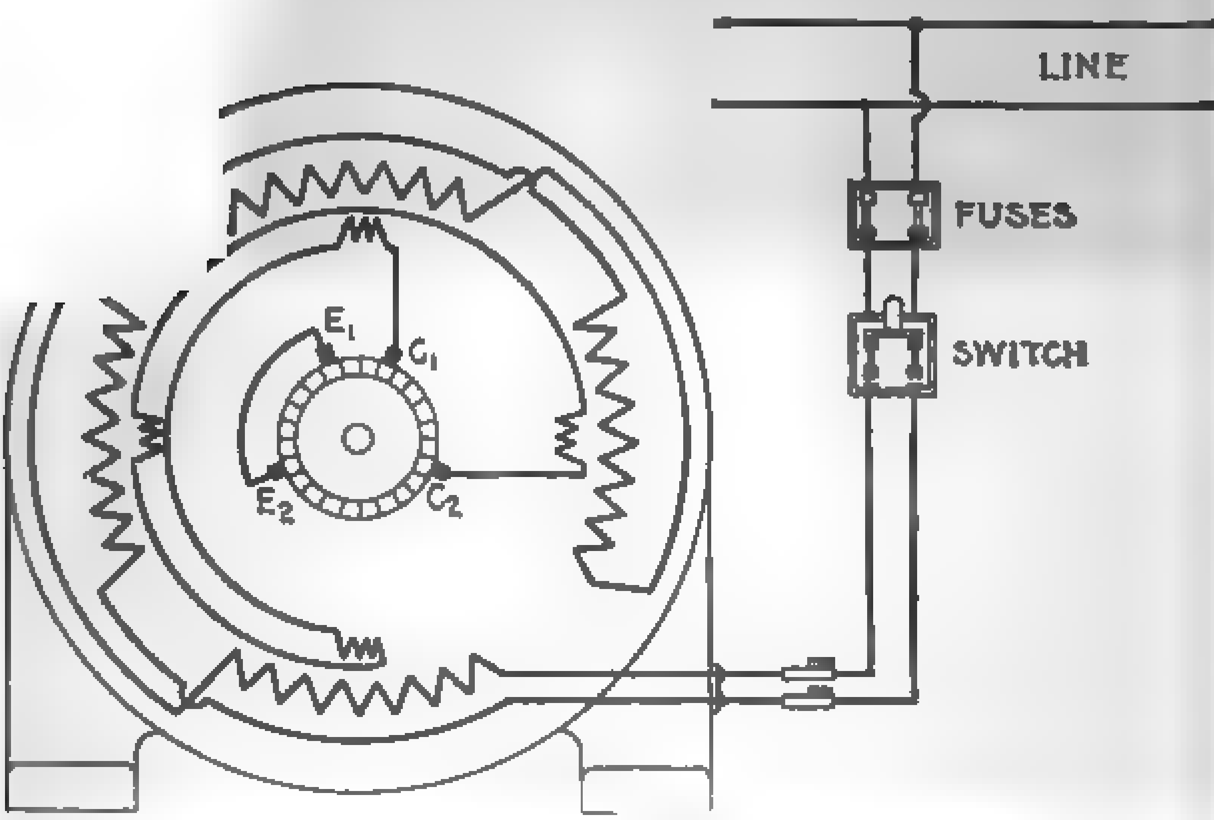


FIG. 1,910.—Diagram of connection of Sprague single phase compensated repulsion motor. To reverse direction of rotation interchange leads C_1 and C_2 and slightly shift the brush holder yoke. Brushes E_1 and E_2 are permanently short circuited. This diagram of connections applies also to fig. 1,911.

Ques. What difficulty was experienced with Thomson's motor?

Ans. Since an open coil armature was used, the torque *developed* was due to only one coil at a time, which involved a *necessarily* high current in the short circuited coil resulting in *heavy sparking*.

Ques. How was this remedied?

Ans. By the use of closed coil armatures in later construction

Ques. Did this effectually stop sparking?

Ans. No.

Ques. What other means is employed in modern designs to reduce sparking?

Ans. Compensation and the use of a distributed field winding, high resistance connectors, high resistance brushes, etc.

Ques. What are the names of the two classes of repulsion motor?

Ans. The simple and the compensated types.

Ques. Describe a simple repulsion motor.

Ans. It consists essentially of an armature, commutator and field magnets. The armature is wound exactly like a direct current armature, and the windings are connected to a commutator. The carbon brushes which rest on this commutator are not connected to the outside line, however, but are all connected together through heavy short circuiting connectors. The brushes are placed about 60° or 70° from the neutral axis. The field is wound exactly like that of the usual induction motor.

Ques. What is the action of this type of motor?

Ans. If nothing be done to prevent, the motor will increase in speed at no load until the armature bursts, just as it will in a series direct current motor.

Ques. What provision is made to avoid this danger?

Ans. A governor is usually mounted on the armature which *short circuits the* windings, after the motor has been started. *The motor then* runs as a squirrel cage induction motor. A

rule the brushes are lifted off the commutator when the arı ture is short circuited, so as to prolong their life.

This is a very successful motor, but it is of course more costly tl the simple squirrel cage motor used on two and three-phase circuits.

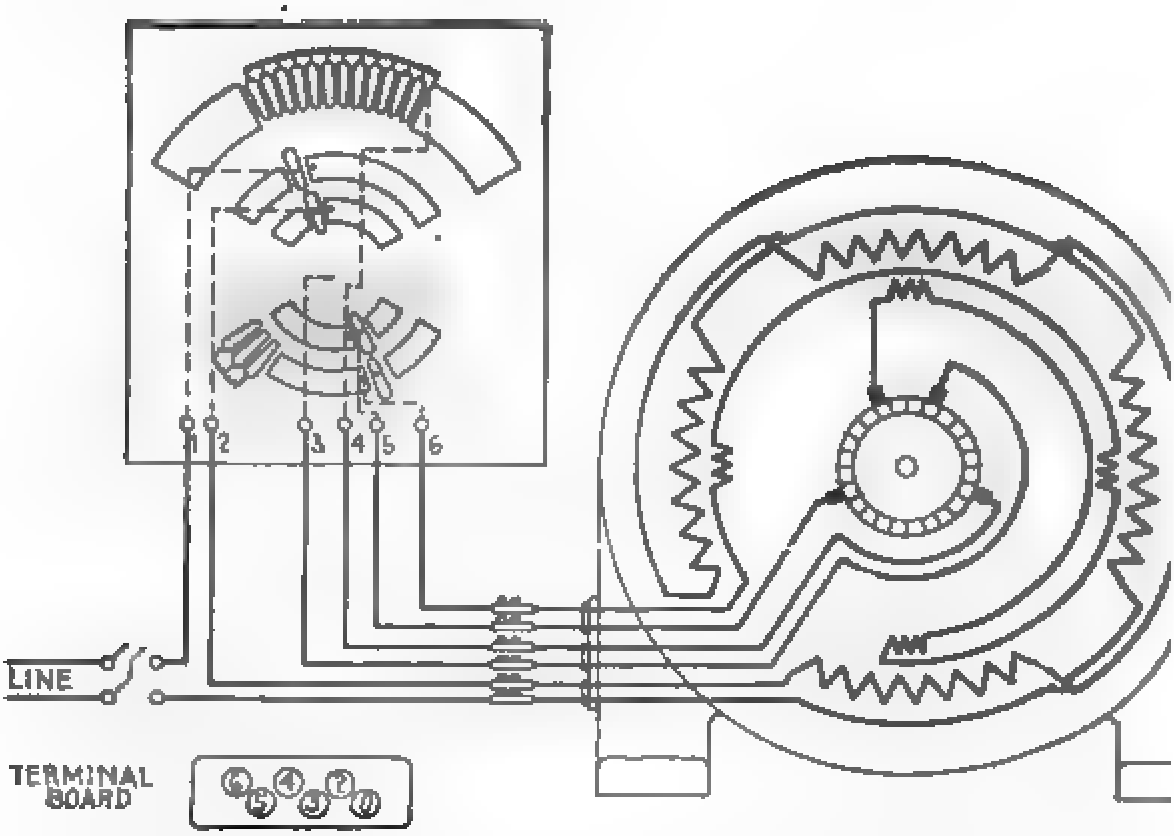


FIG. 1,911.—Diagram of connections of Sprague variable speed single phase compens repulsion motor and controller. The controller is designed to give speed reduction speed increase as resistance or reactance is inserted in the energy and compensa circuits. With the exception of the leads brought out from these circuits, the cons speed and variable speed motors are identical. The standard controller gives appı mately 2 : 1 speed variation.

Ques. What name may appropriately be applied to t motor?

Ans. It may be called the *repulsion induction motor*, becaı it is constructed for repulsion start and induction running.

Ques. Describe a compensated repulsion motor.

Ans. In its simplest form it consists of a simple repuls motor in which there are two independent sets of brushes

set being short circuited, while the other set is in series with the field magnet winding, as in the series alternating current motor.

Ques. What names are given to the two sets of brushes on a compensated repulsion motor?

Ans. The *energy* or main short circuiting brushes, and the *compensating* brushes.

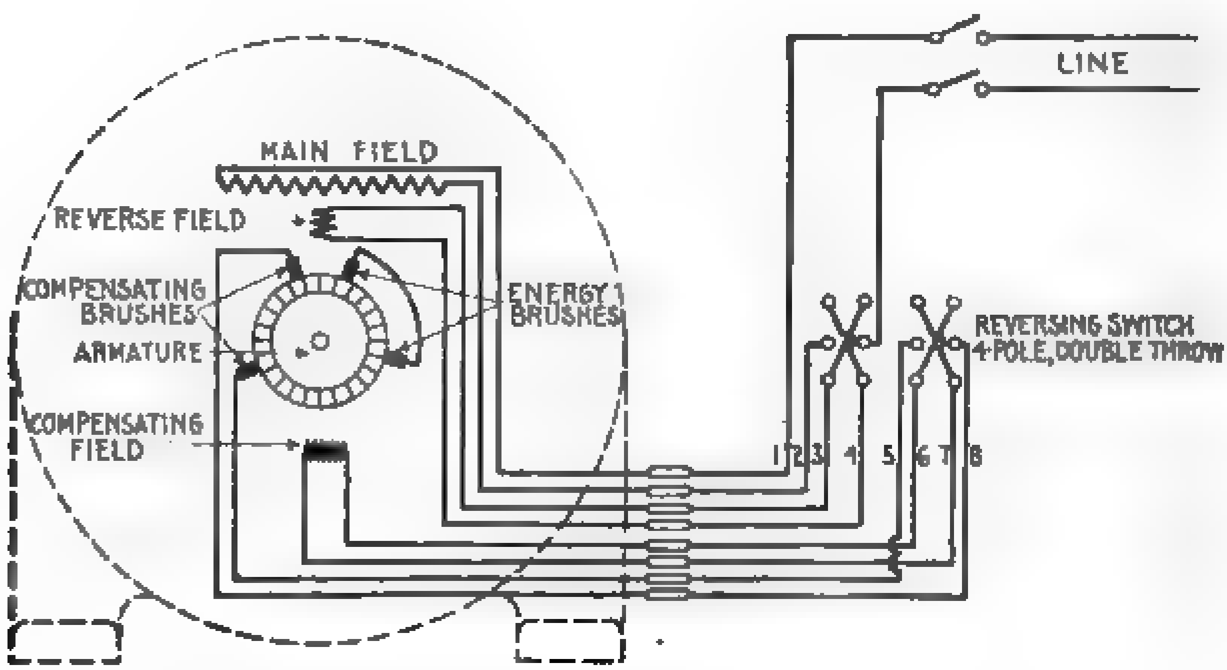


FIG. 1,912.—Diagram of connections of Sprague reversing type of single phase compensated repulsion motor. As shown, there is a special reverse field winding having terminals for connection to a four pole double throw switch.

Ques. What is the behavior of the armature of a compensated repulsion motor at starting?

Ans. It possesses at starting most of the apparent reactance of the motor, and the effect of speed is to decrease such apparent reactance, the latter becoming zero at either positive or *negative synchronism*, and negative at higher speeds in eith *direction*.

Ques. What is the nature of the field circuit of t compensated repulsion motor at starting?

Ans. At starting it is practically non-inductive, the eff of speed being to introduce a spurious resistance which i creases directly with the speed, and becomes negative wh the speed is reversed.

Ques. For what use is the compensated repulsi motor especially adapted?

Ans. For light railroad service.

Ques. When employed thus what is the method control?

Ans. A series transformer is used in the field circuit.

Ques. What frequencies are employed with motor?

Ans. 25 to 60, the preferred frequency being 40.

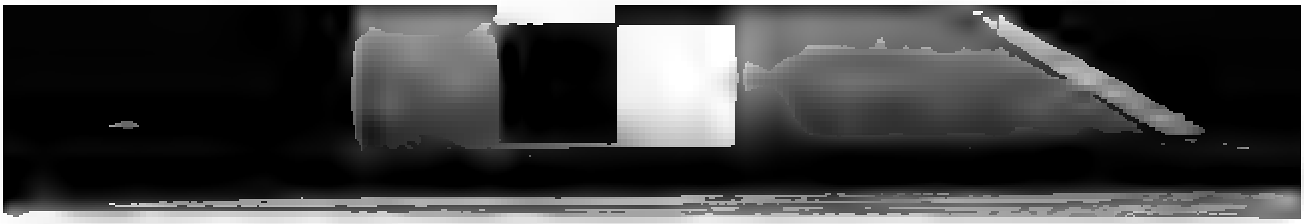
Ques. To what important use is the repulsion prin ciple put?

Ans. It is sometimes employed for starting on single pha induction motors.

In this method, after bringing the motor up to speed, the winding then short circuited upon itself, and the motor then operates on t induction principle.

Ques. What name is given to this type of motor?

Ans. It is called the repulsion induction motor.



Power Factor of Induction Motors.—In the case of a direct current motor, the energy supplied is found by multiplying the current strength by the voltage, but in all induction motors the effect of self-induction causes the current to lag behind the pressure, thereby increasing the amount of current taken by the motor. Accordingly, as the increased current is not utilized by the motor in developing power, the value obtained by multiplying the current by the voltage represents an *apparent energy* which is greater than the real energy supplied to the motor.

IG. 1,913.—Fairbanks-Morse squirrel cage armature, showing ball bearings.

It is evident, that if it were possible to eliminate the lag entirely, the real and apparent watts would be equal, and the power factor would be unity.

The importance of power factor and its effect upon both alternator capacity and voltage regulation is deserving of the most careful consideration with all electrical apparatus, in which *an inherent phase* difference exists between the pressure and the *current, as for instance* in static transformers and induction motors

While the belief is current that any decrease in power factor from unity value does not demand any increase of mechanical output, this is not true, since all internal alternator and line losses manifest themselves as heat, the wasted energy to produce this heat being supplied by the prime mover.

Apart from the poor voltage regulation of alternating current generators requiring abnormal field excitation to compensate for low power factor, some of the station's rated output is rendered

FIG. 1,914.—Fairbanks-Morse 20 horse power squirrel cage induction motor connected to a 20 inch self-feed rip and chamfering saw. The absence of commutator and brushes on the squirrel cage armature eliminates sparking and therefore renders this type of motor particularly adapted for use in places where sparking would be dangerous, such as in wood working plants, textile mills, etc.

unavailable and consequently produces no revenue. The poor steam economy of underloaded engines is also a serious source of fuel wastage.

Careful investigations have shown that the power factor of industrial plants using induction motor drive with units of various sizes will average between 60 and 80 per cent. With plants supplying current to underloaded motors having inherently high lagging current values, a

combined factor as low as 50 per cent. may be expected. Since standard alternators are seldom designed to carry their rated kilowatt load at less than 80 per cent. power factor, the net available output is, therefore, considerably increased.

FIG. 1,915.—Method of casting end rings on squirrel cage armatures of Fairbanks-Morse induction motors. The metal being fused to the bars at a temperature in excess of 1,832 degrees Fahr. It is readily seen that the destructive effect of any subsequent heating is eliminated. While giving the most intimate contact at the joints, a multiplicity of joints is avoided as well as solder.

Speed and Torque of Motors.—The speed of an induction motor depends chiefly on the frequency of the circuit and runs within 5 per cent. of its rated speed; it will produce full torque if the line voltage do not vary more than 5 to 10 per cent.

At low voltage the speed will not be greatly reduced as in a direct current motor, but as the torque is low the motor is easily stopped *when a light load is thrown on.*

The current taken by an induction motor from a consta pressure line varies with the speed as in a direct current mot When a load is thrown on, the speed is reduced correspondin and as the self-induction or reactance is diminished, m current circulates in the squirrel cage winding, which in tu reacts on the field coils in a similar manner and more curr flows in them from the line. In this manner the motor au matically takes current from the line proportional to the lo and maintains a nearly constant speed.

The so-called constant speed motors require slight variatio in speed to automatically take current from the line when t load varies.

Induction motors vary in speed from 5 to 10 per cent., wh synchronous motors vary but a fraction of one per cent.

Single phase motors to render efficient service must be ab where requisite, to develop sufficient turning moment or torq to accelerate, from standstill, loads possessing large inertia excessive static friction; for example, meat choppers and grinde sugar or laundry centrifugals; heavy punch presses; gro driven machines running from countershafts with possibly ov taut belting, poor alignment, lubrication, etc.

CHAPTER LII

TRANSFORMERS

The developments in the field of electrical engineering which have rendered feasible the transmission of high pressure currents over long distances, together with the reliability and efficiency of modern generating units, have resulted in notable economies in the generation and distribution of electric current.

This has been accomplished largely by the use of distant water power or the centralization of the generating plants of a large territory in a single power station.

The transformer is one of the essential factors in effecting the economical distribution of electric energy, and may be defined as *an apparatus used for changing the voltage and current of an alternating circuit.* A transformer consists essentially of:

1. A primary winding;
2. A secondary winding;
3. An iron core.

Basic Principles.—If a current be passed through a coil of wire encircling a bar of soft iron the iron will become a magnet; when the current is discontinued the bar loses its magnetization.

Conversely: If a bar of iron carrying a coil of wire be magnetized in a direction at right angles to the plane of the coil a momentary electric pressure will be induced in the wire; *if the current be reversed,* another momentary pressure will be induced *in the opposite direction* in the coil.

tions are fully explained in chaps. X and XI, and
rfectly familiar phenomena, a detailed explanat
iples upon which they depend is not necessary h

the first two statements given above it is evident that if a
e provided with two coils of wire, one of which is supplied fr
f alternating current, as shown diagrammatically by fig. 1,
impulse of the exciting current a pressure will be induced in
coil, the direction of t.. se impulses alternating like th
ng current.

**What name is given to the coil through wh
om the source flows?**

Ans. *The primary winding.*

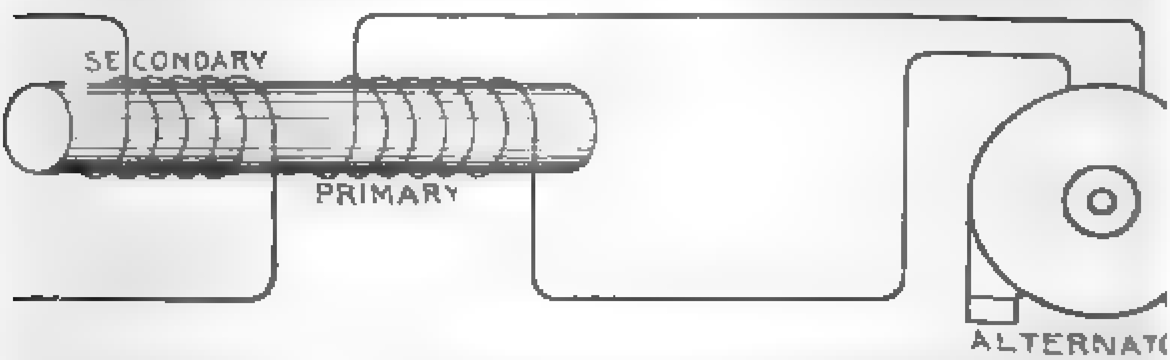


FIG. 1,916.—Diagram of elementary transformer with non-continuous core and connec with single phase alternator The three essential parts are: primary winding, secon winding, and an iron core.

Ques. What name is given to the coil in which current is induced?

Ans. *The secondary winding.*

Similarly, the current from the source (alternator) is called the *prim current* and the induced current, the *secondary current.*

Ques. What is the objection to the elementary tran former shown in fig. 1,916?

Ans. The non-continuous core. With this type core, t *flux* emanating from the north pole of the bar has to retur

the south pole through the surrounding air; and as the reluctance of air is much greater than that of iron, the magnetism will be weak.

Ques. How is this overcome?

Ans. By the use of a continuous core as shown in fig. 1,917.

Ques. Is this the best arrangement, and why?

Ans. No. If the windings were put on as in fig. 1,917, the leakage of magnetic lines of force would be excessive, as indicated by the dotted lines. In such a case the lines which leak through air have no effect upon the secondary winding, and are therefore wasted.

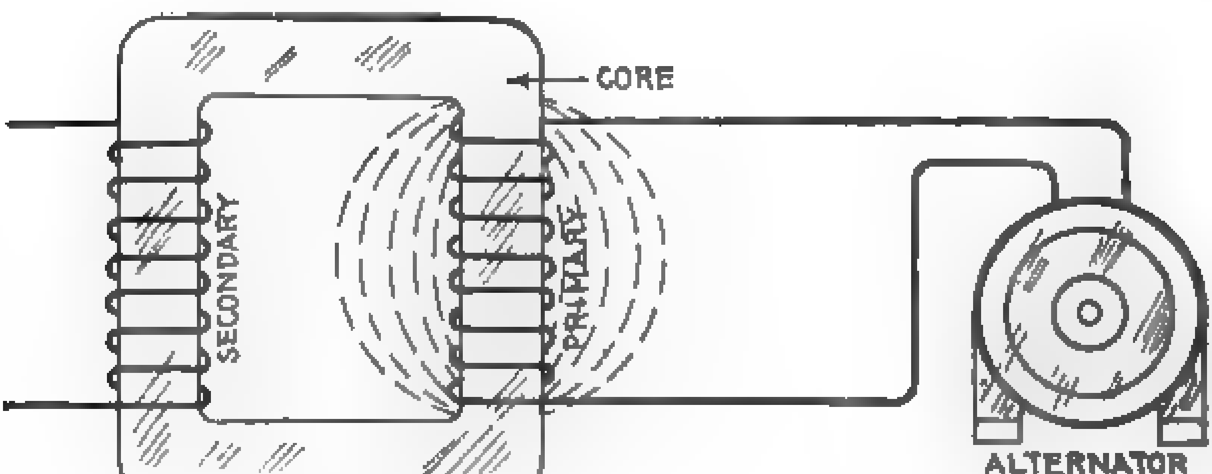


FIG. 1,917.—Diagram of elementary transformer with continuous core and connections with alternator. The dotted lines show the leakage of magnetic lines. To remedy this the arrangement shown in fig. 1,918 is used.

Ques. How is the magnetic leakage reduced to a minimum in commercial transformers?

Ans. In these, and even in ordinary induction coils (the operating principle of which is the same as that of transformers) the magnetic leakage is reduced to the lowest possible amount by arranging the coils one within the other, as shown in cross section in fig. 1,918.

...ced Voltage.—The pressure induced ...ding will depend on the *ratio* between the ... two windings. For example, a transfor... wire in its primary winding and 50 tur... ding would have a transformation ratio of ... supplied with primary current at 1,000 v... ...sure at no load would be 100 volts.

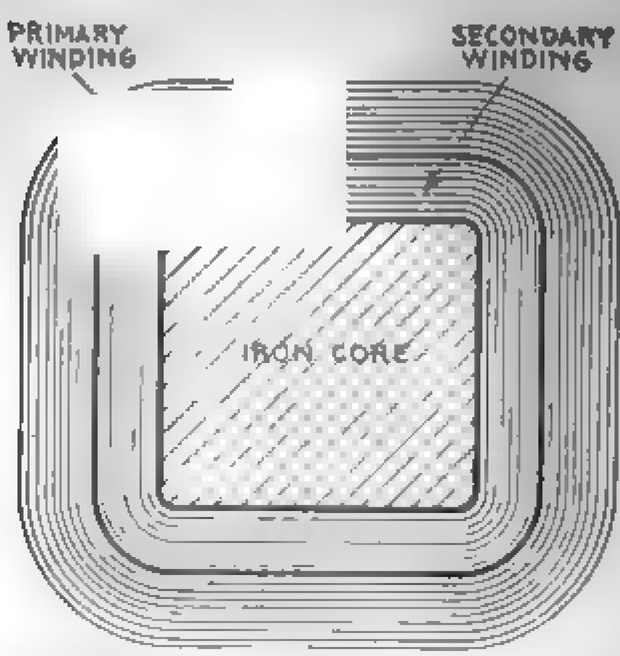


FIG. 1,918.—Cross section showing commercial arrangement of primary and seco... ings on core. One is superposed on the other This arrangement compels all of the magnetic lines created by the primary winding to pass through the ... winding.

EXAMPLE.—If ten amperes flow in the primary winding ... transformation ratio be 10, then $10 \times 10 = 100$ amperes ... through the secondary winding.

Thus, a direct proportion exists between the pressures and ... the two windings and an inverse proportion between the amp... turns, that is:

primary voltage: *secondary voltage* = *primary turns*: *secondary tu...*
primary current: *secondary current* = *secondary turns*: *primary tu...*

From the above equations it is seen that the watts ... *primary* circuit equal the watts of the secondary circui...

Ques. Are the above relations strictly true, and why?

Ans. No, they are only approximate, because of transformer losses.

In the above example, the total wattage in the primary circuit is 1,000 × 10 = 10 kw., and that in the secondary circuit is 100 × 100 = 10 kw. Hence, while both volts and amperes are widely different in the two circuits, the watts for each are the same in the ideal case, that is, assuming perfect transformer action or 100% efficiency. Now, the usual loss in commercial transformers is about 10%, so that the actual watts delivered in the secondary circuit is (100 × 100) × 90% = 9 kw.

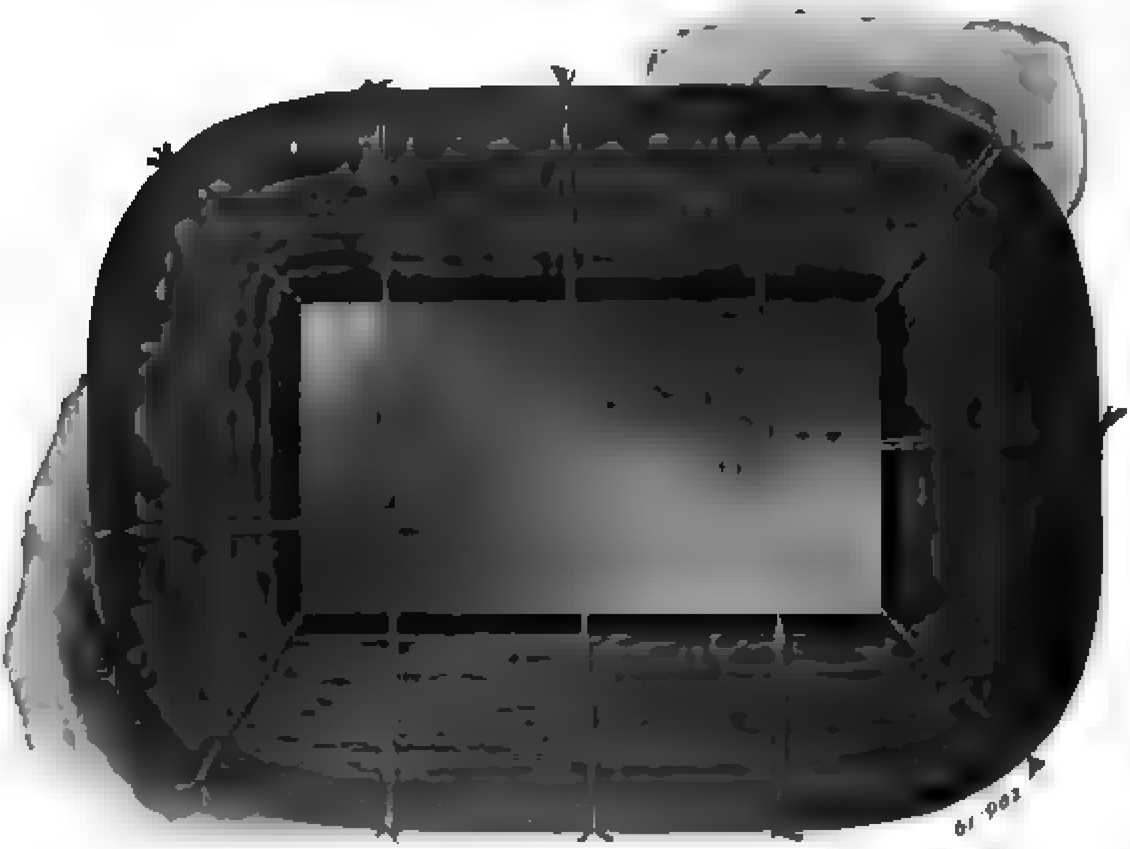


FIG. 1,919.—Wagner transformer coil formed, ready for taping. These are known as "pan cake" coils. They are wound with flat cotton covered copper strip. In heavy coils, several strips in parallel are used per turn in order to facilitate the winding and produce a more compact coil.

The No Load Current.—When the secondary winding of a transformer is open or disconnected from the secondary *circuit no current* will flow in the winding, but a very smal *current called the no load current* will flow in the primary circ

The reason for this is as follows: The current flowing in the primary winding causes repeated reversals of magnetic flux through the iron core. These variations of flux induce pressures in both coils; that induced in the primary called the *reverse pressure* is opposite in direction

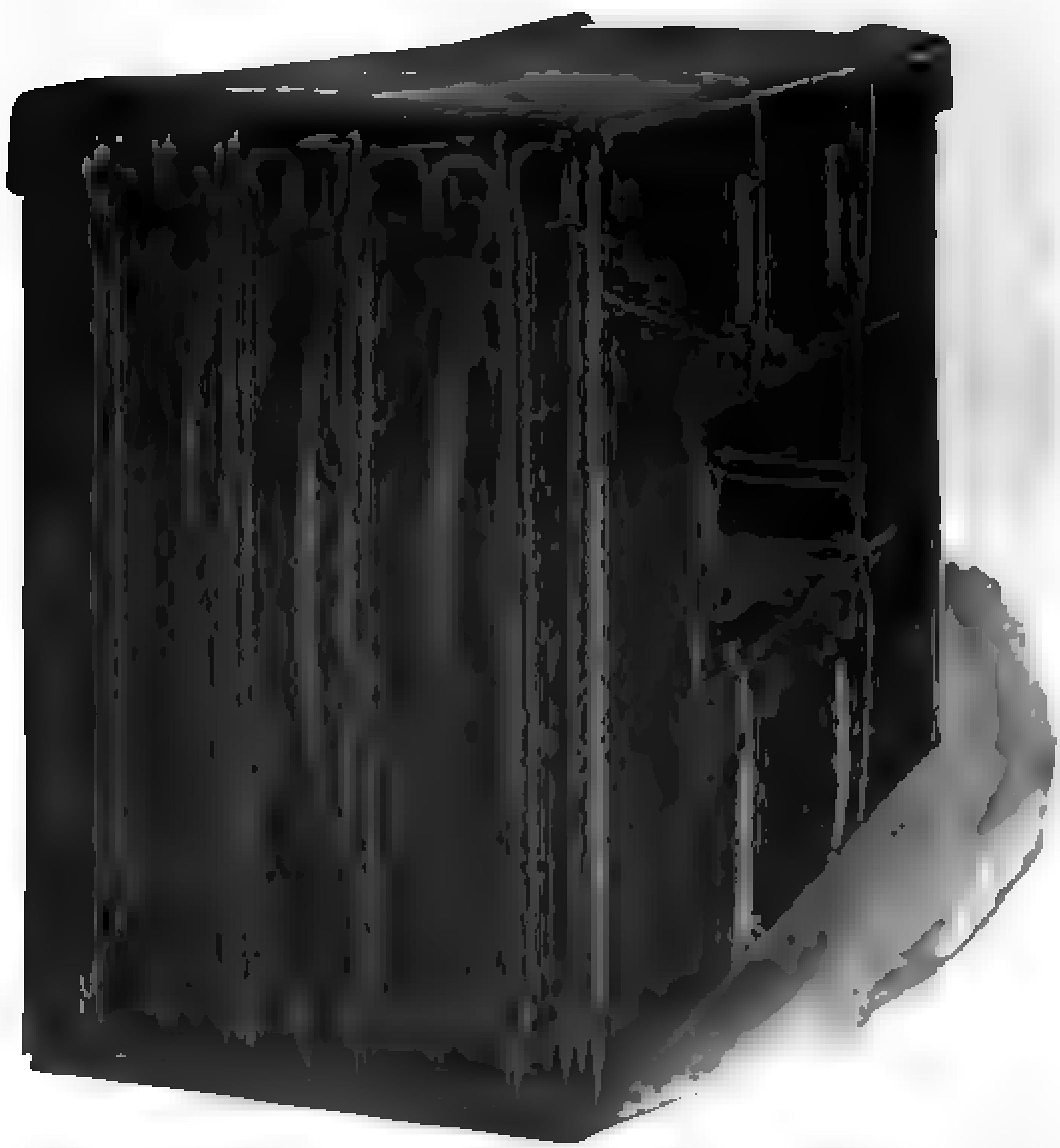


FIG. 1,920. Wagner coils with insulation ready for core assembly. The flat coils, sometimes called pancake coils, are wound of flat, cotton covered, copper strip with ample insulation between layers. In heavy coils several flat strips in multiple are used per turn in order to facilitate the winding and produce a more compact coil. In many cases normal current flow per high tension coil is very low and could be carried with a very small cross sectional area of copper, however, flat strip is almost always used on account of the increased mechanical stability thus obtained.

and very nearly equal to the impressed pressure, that is, to the pressure *applied* to the primary winding. Accordingly the only force available to *cause* current to flow through the primary winding is the difference *between* the impressed pressure and reverse pressure, the *effective pressure*.

The Magnetizing Current.—The magnetizing current of a transformer is sometimes spoken of as that current which the primary winding takes from the mains when working at normal pressure. The *true magnetizing current* is only that component of this total no load current which is in quadrature with the supply pressure. The remaining component has to overcome the various iron losses, and is therefore an "in phase" component. The relation between these two components determines the power factor of the so called "magnetizing current."

FIGS. 1,921 and 1,922.—Assembled coils of Westinghouse 10 and 15 kva. transformers; views showing ventilating ducts.

The true magnetizing component is small if the transformer be well designed, and be worked at low flux density.

Action of Transformer with Load.—If the secondary winding of a transformer be connected to the secondary circuit by closing a switch so that current flows through the secondary winding, the transformer is said to be *loaded.*

The action of this secondary current is to *oppose the magnetizing action of the slight* current already flowing in the primary winding, thus *decreasing the maximum value reached by the alternating magnetic flux in the core, thereby decreasing the induced pressure in each winding.*

The amount of this decrease, however, is *very small*, inasmuch as a very small decrease of the induced pressure in the primary coil greatly increases the difference between the pressure applied to the primary coil and the opposing pressure induced in the primary coil, so that the primary current is greatly increased. In fact, ***the increase of primary current due to the loading of the transformer is just great enough (or very nearly) to exactly balance the magnetizing action of the current in the***

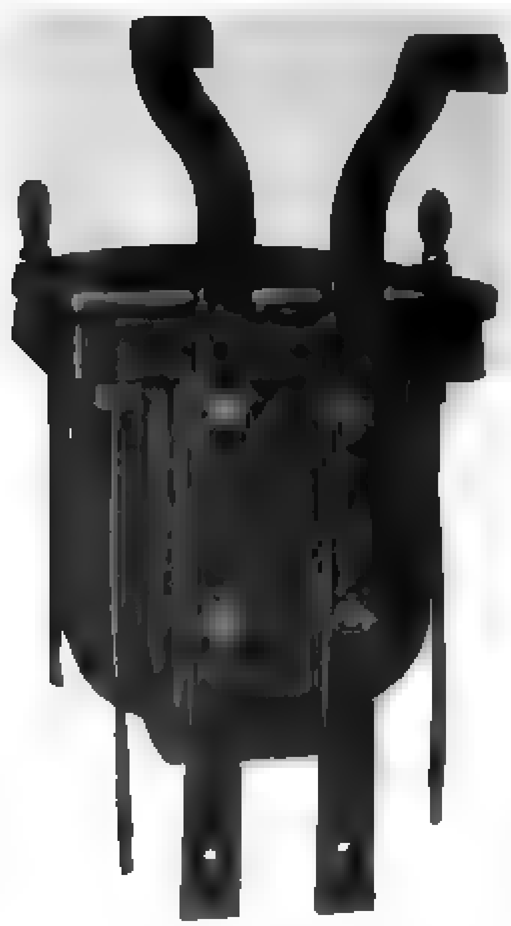


FIG. 1,923.—Rear view of Fort Wayne distributing transformer, showing hanger irons for attaching to pole cross arm.

secondary coil; that is, the flux in the core must be maintained approximately constant by the primary current whatever value the secondary current may have.

When the load on a transformer is increased, the primary of the transformer automatically takes additional current and power from the supply mains in direct proportion to the load on the secondary.

When the load on the secondary is reduced, for example by turning off lamps, the power taken from the supply mains by the primary coil *is automatically* reduced in proportion to the decrease in the load. *This* automatic action of the transformer is due to the balanced *magnetizing* action of the primary and secondary currents.

Classification of Transformers.—As in the case of motors, the great variety of transformer makes it necessary that a classification, to be comprehensive, must be made from several points of view, as:

1. With respect to the transformation, as

   a. Step up transformers;
   b. Step down transformers.

2. With respect to the arrangement of the coils and magnetic circuit, as

   a. Core transformers;
   b. Shell transformers;
   c. Combined core and shell transformers.

3. With respect to the kind of circuit they are to be used on, as

   a. Single phase transformers;
   b. Polyphase transformers.

4. With respect to the method employed in cooling, as

   a. Dry transformers;
   b. Air cooled transformers { natural draught; forced draught, or air blast;
   c. Oil cooled transformers;
   d. Water cooled transformers.

5. With respect to the nature of their output, as

   a. Constant pressure transformers;
   b. Constant current transformers;
   c. Current transformers;
   d. Auto-transformers.

6. With respect to the kind of service, as

   a. *Distributing;*
   b. *Power.*

, to the circuit connection that the trans- ... ted for, as

... ansformers;
... transformers.

...ansformers.—This form of transformer is used ... a low voltage current ... o a high voltage current. ... ormers are employed at the generating end of a ... mission line to raise the voltage of the alternators to such

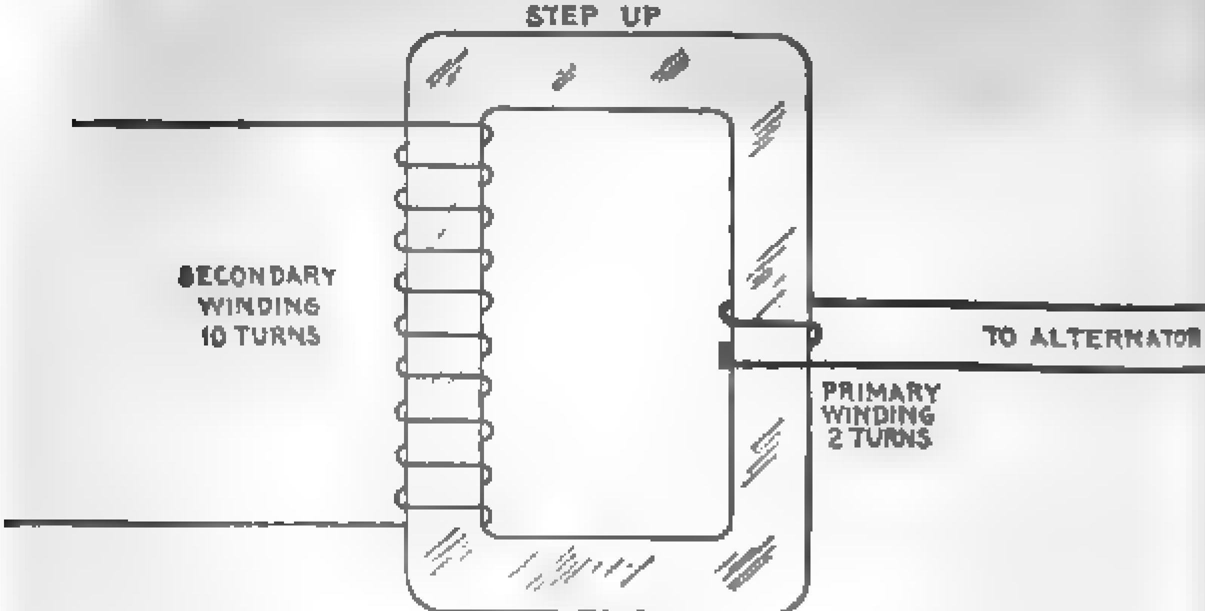


FIG. 1,924.—Diagram of elementary *step up* transformer. As shown the primary winding has two turns and secondary 10 turns, giving a ratio of voltage transformation of $10 \div 2 = 5$. Since only ... as much current flows in the secondary winding as in the primary, the latter requires heavier wire than the former.

value as will enable the electric power to be economically transmitted to a distant point.

Copper Economy with Step Up Transformers.—To comprehend fully the bearing of the matter, it must be remembered that the energy supplied per second is the product of two factors, the current and the pressure at which that current is supplied; the magnitudes of the two *factors may vary*, but the value of the power supplied depends only on *the product* of the two; for example, the energy furnished per second by a current of 10 amperes supplied at a pressure of 2,000 volts ...

exactly the same in amount as that furnished per second by a current of 400 amperes supplied at a presure of 50 volts; in each case, the product is 20,000 watts.

Now the loss of energy that occurs in transmission through a well insulated wire depends also on two factors, the current and the resistance of the wire, and in a given wire is proportional to the square of the current. In the above example the current of 400 amperes, if transmitted through the same wire as the 10 amperes current, would, because it is forty times as great, waste sixteen hundred times as much energy in heating the wire. It follows that, for the same loss of energy, the 10 ampere current at 2,000 volts may be carried by a wire having only

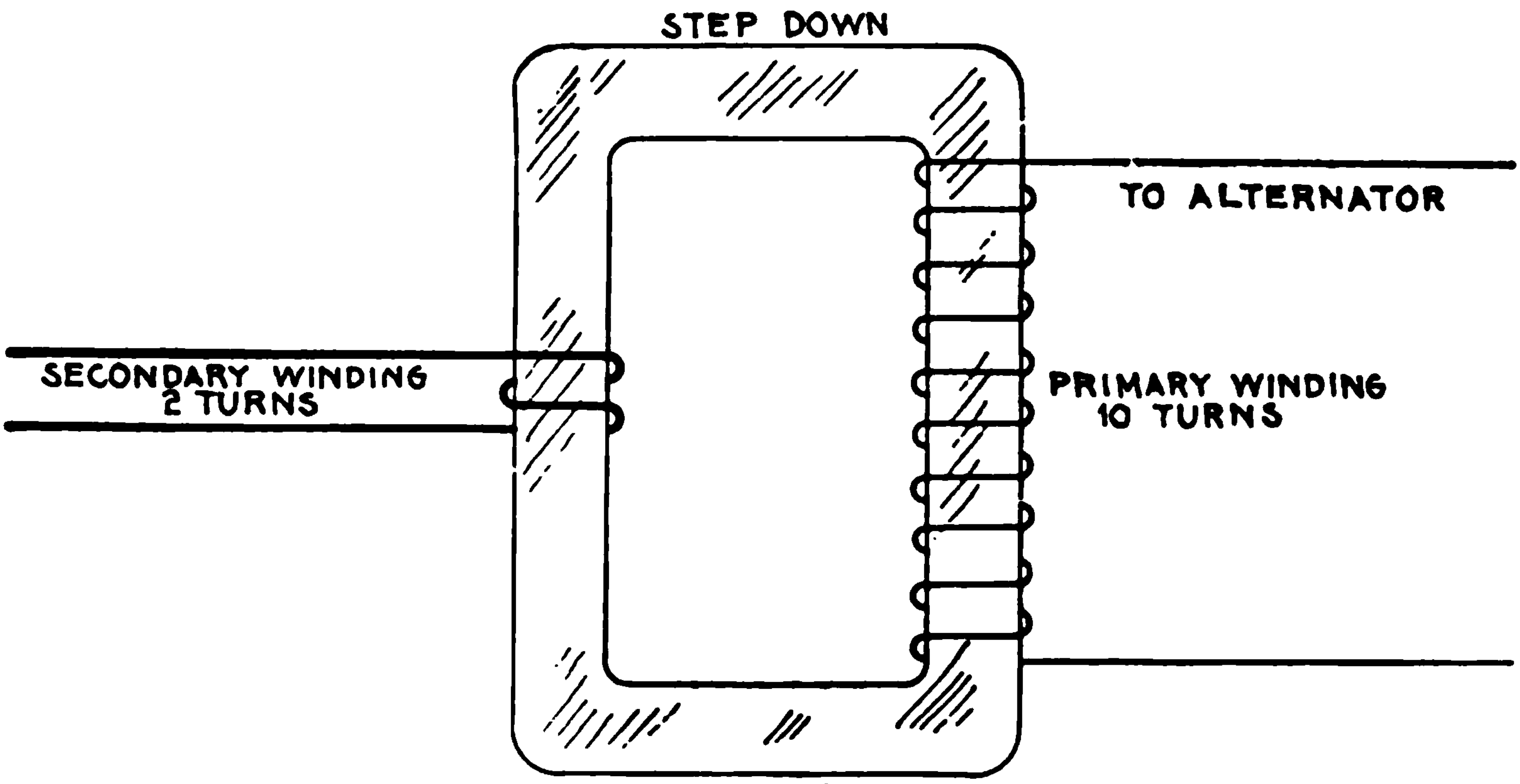


Fig. 1,925.—Diagram of elementary step down transformer. As shown the primary winding has 10 turns and the secondary 2, giving a ratio of voltage transformation of 2 + 10 = .2. The current in the secondary being 5 times greater than in the primary will require a proportionately heavier wire.

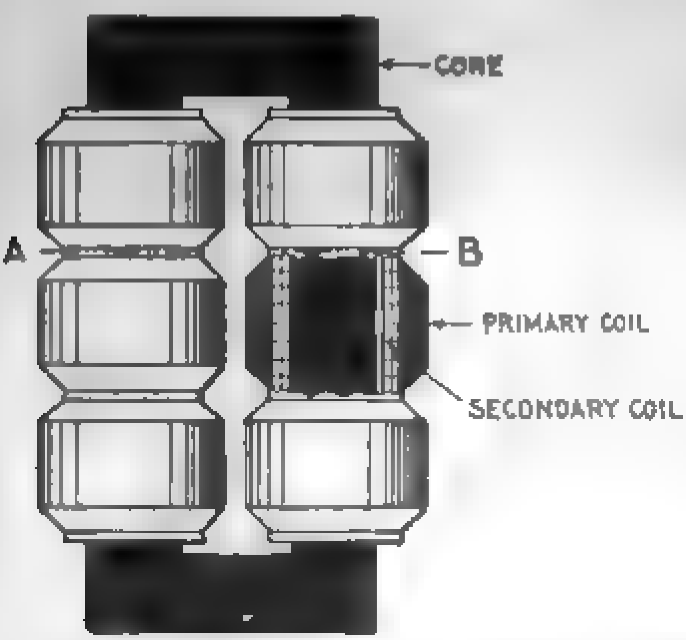
$\frac{1}{1,600}$th of the sectional area of the wire used for the 400 ampere current at 50 volts.

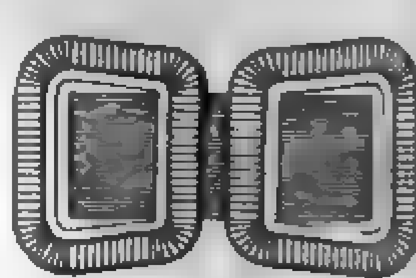
The cost of copper conductors for the distributing lines is therefore very greatly economized by employing high pressures for distribution of small currents.

Step Down Transformers.—When current is supplied to *consumers for lighting* purposes, and for the operation of motors *etc., considerations* of safety as well as those of suitabili

require the delivery of the current at comparatively low pressure ranging from 100 to 250 volts for lamps, and from 100 to 600 volts for motors.

This involves that the high pressure current in the transmission lines must be transformed to low pressure current at the receiving or distributing points by *step down transformers*, an elementary transformer being shown in fig. 1,925.

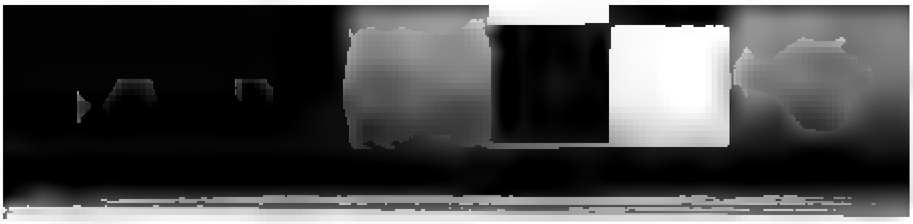




FIGS. 1,926 and 1,927.—Core type transformer. It consists of a central core of laminated iron, around which the coils are wound. A usual form of core type transformer consists of a rectangular core, around the two long limbs of which the primary and secondary coils are wound, the low tension coil being placed next the core.

Transformers of this type have a large number of turns in the primary winding and a small number in the secondary, in ratio depending on the amount of pressure reduction required.

Core Transformers.—This type of transformer may be defined as one having an iron core, upon which the wire is wound in such a manner that the iron is enveloped within the *coils, the* outer surface of the coils being exposed to the air as *shown in figs.* 1,926 and 1,927.



Shell Transformers.—In the shell type of transformer, as shown in fig. 1,928, the core is in the form of a shell, being built around and through the coils. A shell transformer has, as a rule, fewer turns and a higher voltage per turn than the core type.

Ques. What is the comparison between core and shell transformers?

Ans. The relative advantages of the two types has been the subject of considerable discussion among manufacturers; the

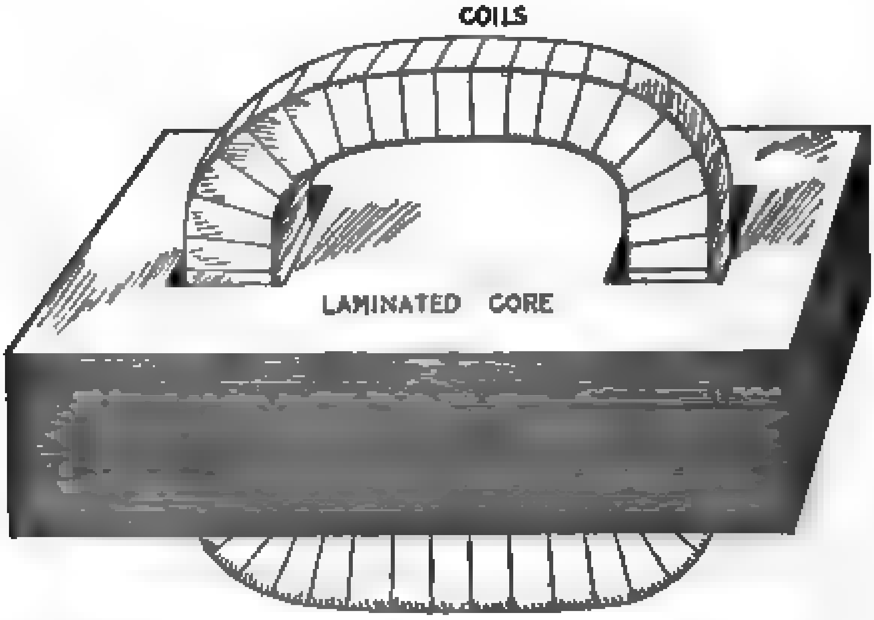


FIG. 1,928.—Shell type transformer. In construction the laminated core is built around and through the coils as shown. For large ratings this type has some advantages with respect to insulation, while for small ratings the core type is to be preferred in this respect. The shell arrangement of the core gives better cooling; with this arrangement minimum magnetic leakage is easily obtained.

companies who formerly built only shell type transformers, now build core types, while with other builders the opposite practice obtains.

Ques. Upon what does the choice between the two types chiefly depend?

Ans. Upon manufacturing convenience rather than operating characteristics.

The major insulation in a core type transformer consists of several large pieces of great mechanical strength, while in the shell type, there are required an extremely large number of relatively small pieces of insulating material, which necessitates careful workmanship to prevent defects in the finished transformer, when thin or fragile material is used.

Both core and shell transformers are built for all ratings; for small ratings the core type possesses certain advantages with reference to insulation, while for large ratings, the shell type possesses better cooling properties, and has less magnetic leakage than the core type.

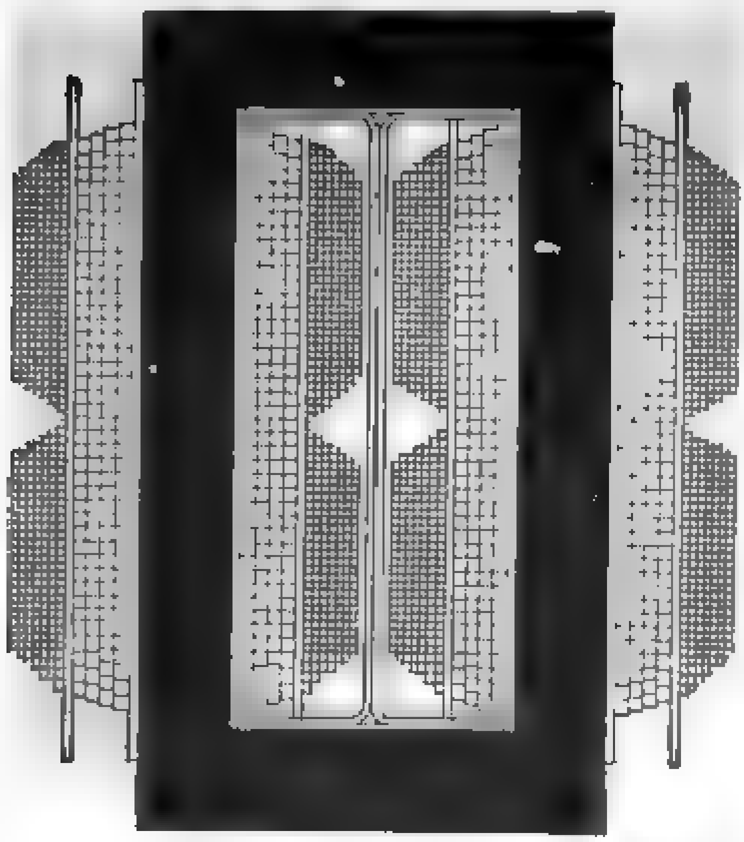
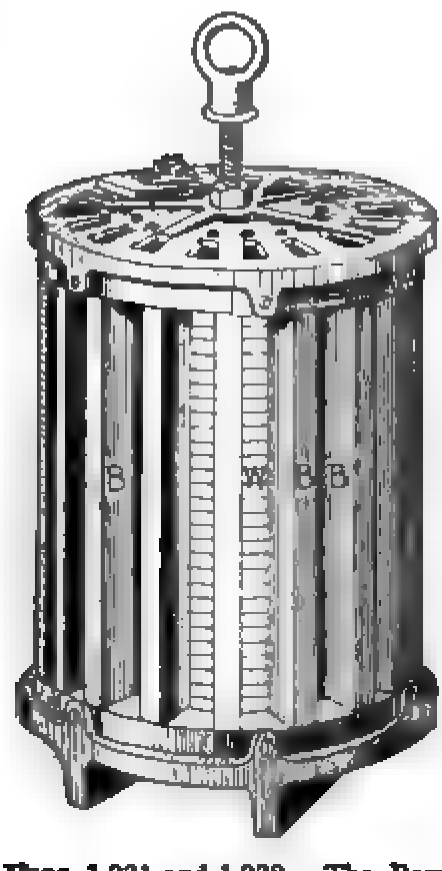


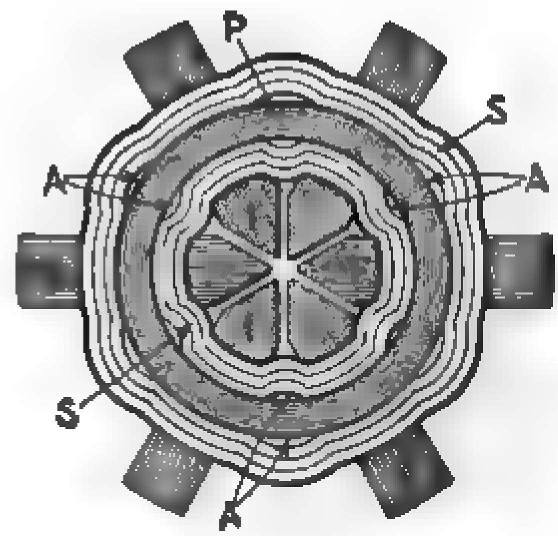
FIG. 1,929.—View illustrating the construction of cores and coils of Maloney transformers.

FIG. 1,930.—Maloney mica shield between primary and secondary coils, showing lapping feature which prevents the wrinkling and cracking of the mica.

Combined Core and Shell Transformers.—An improved type of transformer has been introduced which can be considered either as two superposed shell transformers with coils in common, or as a single core type transformer with divided magnetic circuit and having coils on only one leg. It is best considered however, as a combined core and shell transformer.

and for small sizes it possesses most of the advantages of both types. It can be constructed at less cost than can either a core or a shell transformer having the same operating characteristics and temperature limits.





FIGS. 1,931 and 1,932.—The Berry combined core and shell transformer. It consists of a number of inner and outer vertical and radial laminated iron blocks built up of the usual thin sheet iron, with the coils between. The magnetic circuit is completed at the top and bottom by other laminated blocks placed horizontally, and the whole is held together between top and bottom cast iron frame plates by a bolt passing right down the center. Fig. 1,931 gives a general view, W being the winding, and B, B, B, etc., the outer laminated blocks. The construction will be better understood from fig. 1,932, where it may be supposed that the top cap and laminated cross pieces have been removed. Here I,I,I and O,O,O are respectively the inner and outer radial vertical blocks, P the primary, and S, S the secondary; the latter being in two sections with the primary sandwiched between, as an extra precaution against shock. It will be evident that this form of transformer possesses excellent ventilation; and this is still further enhanced by opening out the winding at intervals to leave ventilating apertures, as at A, A, A. Fig. 1,932 shows only 6 sets of radial blocks, but the usual plan is to provide 24 or 36, according to the size of the transformer.

Fig. 1,932 shows a cross section of the first transformer of this type to be developed commercially, and known as an "iron clad" transformer; this construction has been used in England for some time. Fig. 1,933 shows the American practice.

Ques. How is economy of construction obtained designing combined core and shell transformers?

Ans. The cross section of iron in the central leg of the c is made somewhat less than that external to the coils, in or to reduce the amount of copper used in the coils.

Single and Polyphase Transformers.—A single ph transformer may be defined as *one having only one set of prim and secondary terminals, and in which the fluxes in the one or s*

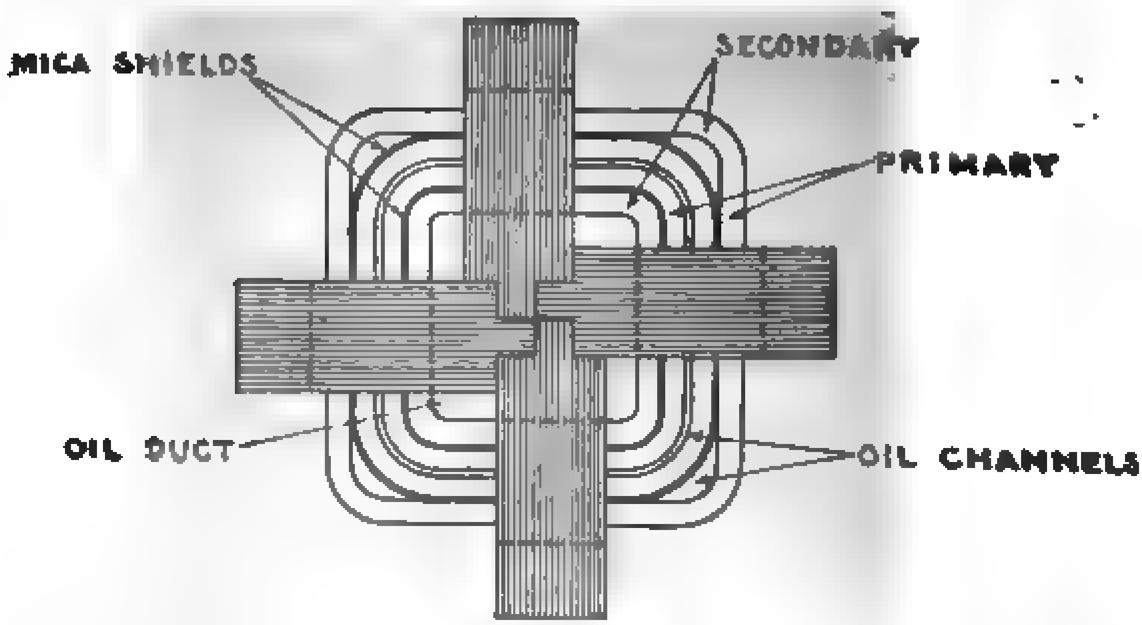


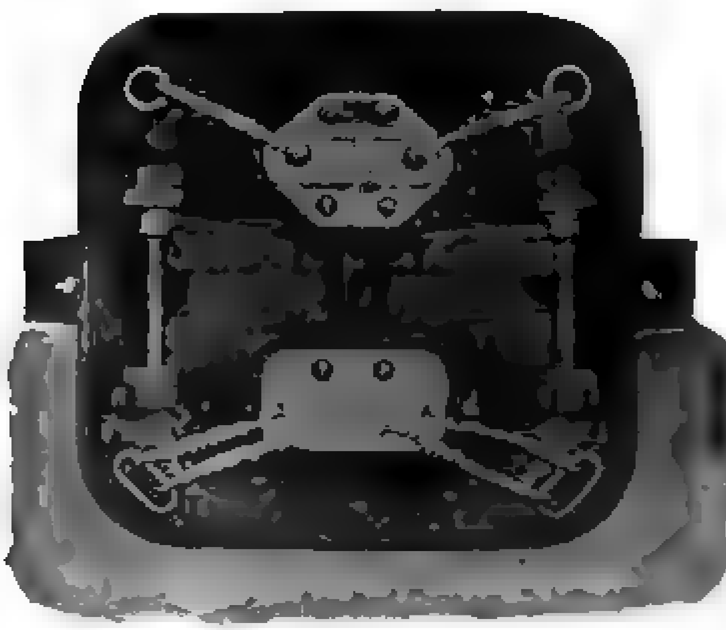
FIG. 1,933.—Plan of Core of General Electric combined core and shell transformer. The used contains four magnetic circuits of equal reluctance, in multiple; each circuit co ing of a separate core. In this construction one leg of each circuit is built up of tw ferent widths of punchings forming such a cross section that when the four circuit assembled together they interlock to form a central leg, upon which the winding is pl The four remaining legs consist of punchings of equal width. These occupy a po surrounding the coil at equal distances from the center, on the four sides; formi channel between each leg and coil, thereby presenting large surfaces to the oil and a ing its free access to all parts of the winding. The punchings of each size transforme all of the same length, assembled alternately, and forming two lap joints equally distrib in the four corners of the core, thereby giving a magnetic circuit of low reluctance.

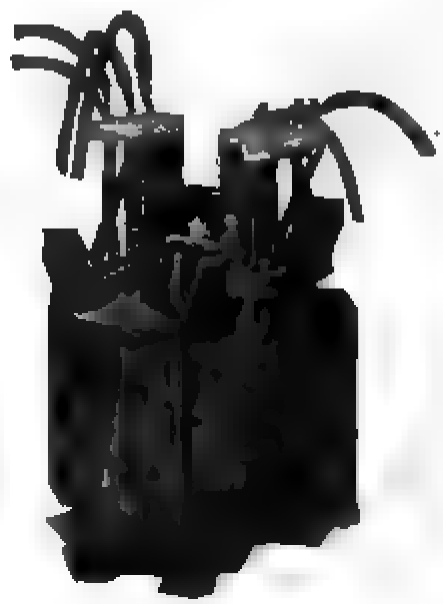
magnetic circuits are all in phase, as distinguished from a po phase transformer, or combination in one unit of several *phase* transformers with separate electric circuits but having *tain* magnetic circuits in common. In polyphase transfo

there are two or more magnetic circuits through the core, and the fluxes in the various circuits are displaced in phase.

Ques. Is it necessary to use a polyphase transformer to transform a polyphase current?

Ans. No, a separate single phase transformer may be used for each phase.

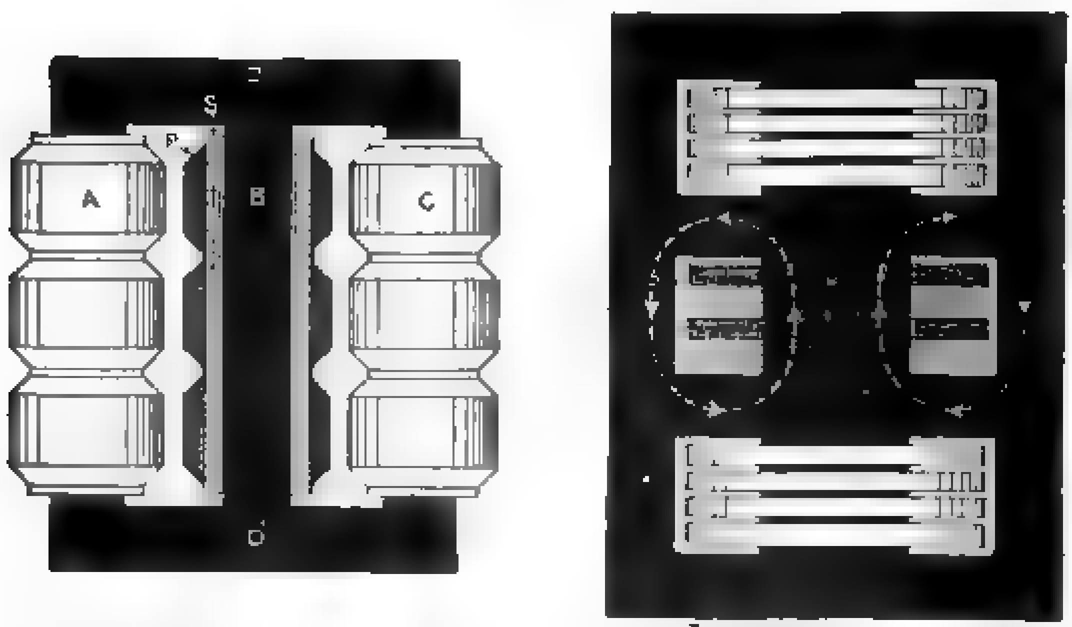




FIGS. 1,934 and 1,935.—Top view showing core and coils in place, and view of coils of Westinghouse distributing transformer. The coils are wound from round wire in the smaller sizes of transformers and from strap copper in the larger sizes. Strap wound coils allow a greater current carrying conductor section than coils wound from large round wire, as there is little waste space between the different turns of the conductor. The coils are arranged concentrically with the high tension winding between the two low tension coils, this arrangement giving the fine regulation found in these transformers. The low tension coils are wound in layers which extend across the whole length of the coil opening in the iron, while the high tension coils are wound in two parts and placed end to end. This construction reduces the normal voltage strains to a value which will not give trouble under any condition of service. The magnetic circuit is built up of laminated, alloy steel punchings, each layer of laminæ being reversed with reference to the preceding layer and all joints butted. This gives a continuous magnetic circuit of low reluctance, low iron loss and low exciting current. When assembled, the magnetic circuit consists of four separate parallel circuits encircling the coils and protecting the windings from mechanical injury. Separate high and low tension terminal blocks of glazed porcelain are mounted upon extensions of the upper end frames. All danger of confusing the leads or inadvertently making an electrical connection between the high and low tension sides of the transformer is thus averted. The high tension winding has four leads brought to the studs in the terminal block. Adjustable brass connectors or links between the studs provide for series or multiple connections between two points of the high tension winding. *The position of the studs* and the length of the links are so proportioned that wrong connections on the block are impossible. Barriers on the porcelain block separate the leads and prevent danger of arcing. Leads with means of preventing creeping of oil by capillary action are attached to these studs and brought out of the core through porcelain [illegible]

Ques. Is there any choice between a polyphase transformer and separate single phase transformers for transforming a polyphase current?

Ans. Yes, the polyphase transformer is preferable, because less iron is required than would be with the several single phase transformers. The polyphase transformer therefore is somewhat lighter and also more efficient.



Figs. 1,936 and 1,937.—Core and shell types of three phase transformer. In the core type, fig. 1,936, there are three cores A, B, and C, joined by the yokes D and D'. This forms a three phase magnetic circuit, since the instantaneous sum of the fluxes is zero. Each core is wound with a primary coil P, and a secondary coil S. As shown, the primary winding of each phase is divided into three coils to ensure better insulation. The primaries and secondaries may be connected *star* or *mesh*. The core B has a shorter return path than A and C, which causes the magnetizing current in that phase to be less than in the A and C phases. This has sometimes been obviated by placing the three cores at the corners of an equilateral triangle (as in figs. 1,939 and 1,940), but the extra trouble involved is not justified, as the unbalancing is a no load condition, and practically disappears when the transformer is loaded The shell type, fig. 1,937, consists practically of three separate transformers in one unit. The flux paths are here separate, each pair of coils being threaded by its own flux, which does not, as in the core type, return through the other coils. This gives the shell type an advantage over the core type, for should one phase burn out, the other two may still be used, especially if the faulty coils be short circuited. The effect of such short circuiting is to prevent all but a very small flux from threading the faulty coil.

Ques. Name two varieties of polyphase transformer?

Ans. The core, and the shell types as shown in figs. 1,936 and 1,937.

Ques. How should a three phase transformer be operated with one phase damaged?

Ans. The damaged windings should be separated electrically from the other coils.

The pressure winding of the damaged phase should be short circuited upon itself and the corresponding low pressure winding should also be short circuited upon itself. The winding thus short circuited will choke down the flux passing through the portion of the core surrounded by them without producing in any portion of the winding a current greater than a small fraction of the current which would normally exist in such portion at full load.

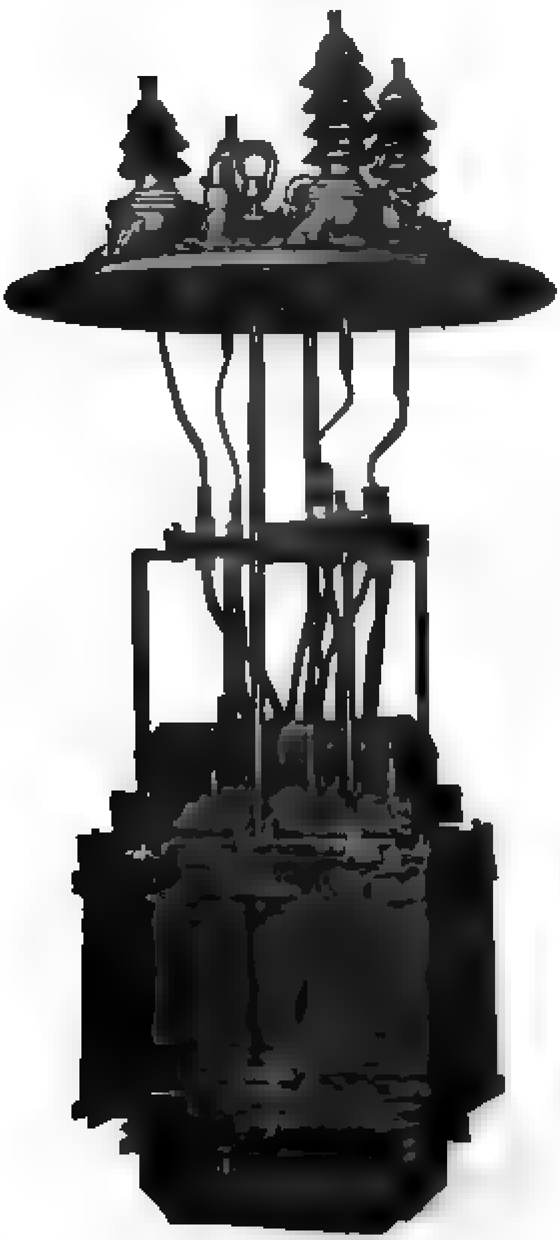


Fig. 1,038.—Interior of **General Electric oil** *cooled 500 kva.* **33,000 volt outdoor** *transformer showing lifting* **arrangement.**

Transformer Losses.—As previously mentioned, the ratio between the applied primary voltage and the secondary terminal voltage of a transformer is not always equal to the ratio of primary to secondary turns of wire around the core.

The commercial transformer is not a perfect converter of energy, that is, the **input**, or watts applied to the primary circuit is always more than the **output** or watts delivered from the secondary winding.

This is due to the various losses which take place, and

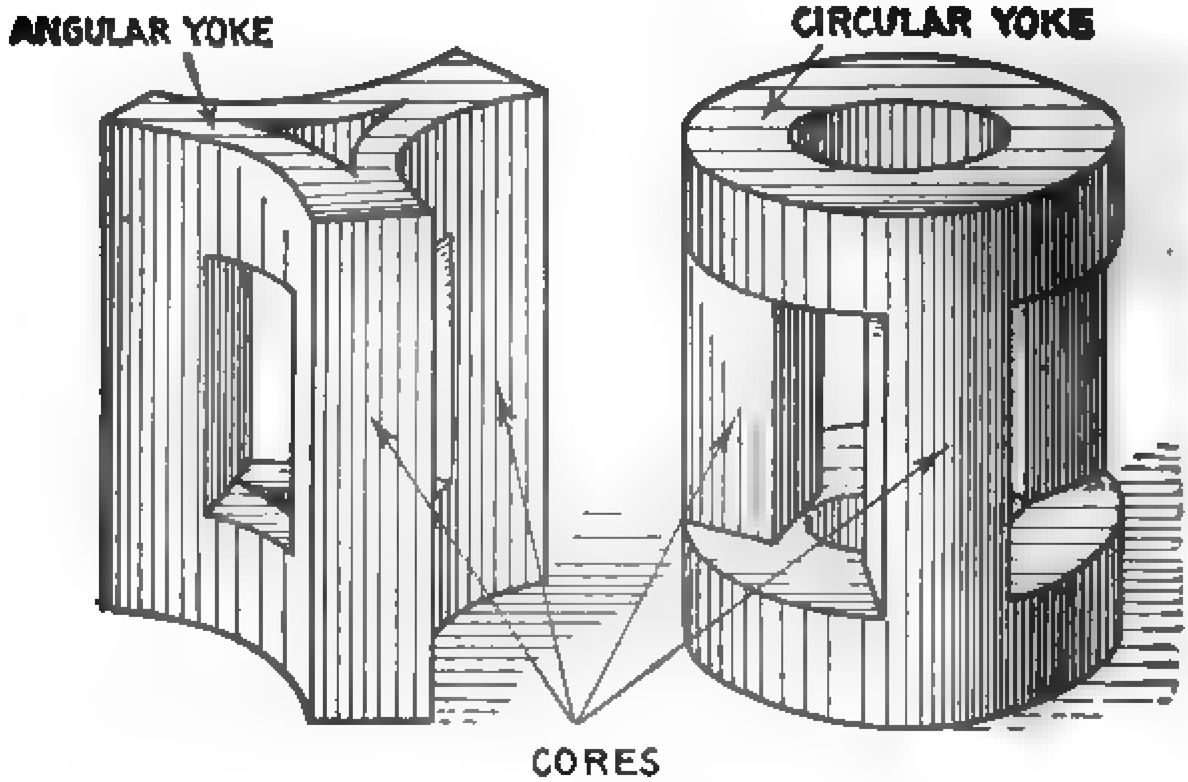
[redacted]

difference between the input and the output is equal to the sum of these losses. They are divided into two classes:

1. The iron or core losses;
2. The copper losses.

The iron or core losses are due to

1. Hysteresis;



FIGS. 1,939 and 1,940.—Triangular arrangements of cores of three phase transformer. Fig. 1,939, form with three cornered yokes at bottom and top of cores; fig. 1,940, form with circular yokes. While these designs give perfect symmetry for the three phases, there is some trouble in the mechanical arrangement of the yokes. If these be stamped out triangularly and inserted horizontally between the three cores, it is necessary to interpose a layer of insulation, otherwise there would be objectionable eddy currents formed in the stampings.

2. Eddy currents;
3. Magnetic leakage (negligibly small).

Those which are classed as copper losses are due to

1. Heating the conductors (the I^2R loss).
2. Eddy currents in conductors.

Hysteresis.—In the operation of a transformer the alternating current causes the core to undergo rapid reversals of magnetism. This requires an expenditure of energy which is converted into heat.

This loss of energy as before explained is due to the work required to change the position of the molecules of the iron,

FIG. 1,941.—View showing mechanical construction of coil and core of Moloney pole type ½ to 50 kw. transformer. Moloney standard transformers of these sizes are regularly wound for 1,100 to 2,200 primary volts. For 1,100 volts the primary coils are connected in parallel by means of connecting links, for 2,200 volts, they are connected in series. The porcelain primary terminal board is provided with two connecting links so that connections can be made for either 1,100 or 2,200 volts.

in reversing the magnetization. Extra power then must be taken from the line to make up for this loss, thus reducing the efficiency of the transformer.

Ques. Upon what does the hysteresis loss depend?

Ans. Upon the quality of the iron in the core, the magnetic density at which it is worked and the frequency.

Ques. With a given quality of iron how does the hysteresis loss vary?

Ans. It varies as the 1.6 power of the voltage with constant frequency.

Ques. In construction, what is done to obtain minimum hysteresis loss?

Ans. The softest iron obtainable is used for the core, and a low degree of magnetization is employed.

FIG. 1,942.—Port Wayne transfor coils and core complete.

Eddy Currents.—The iron core of a transformer acts as a closed conductor in which small pressures of different valu are induced i different parts by tl alternating field, gi ing rise to eddy cu rents. Energy is thu consumed by the currents which wasted in heating tl iron, thus reducin the efficiency of tl transformer.

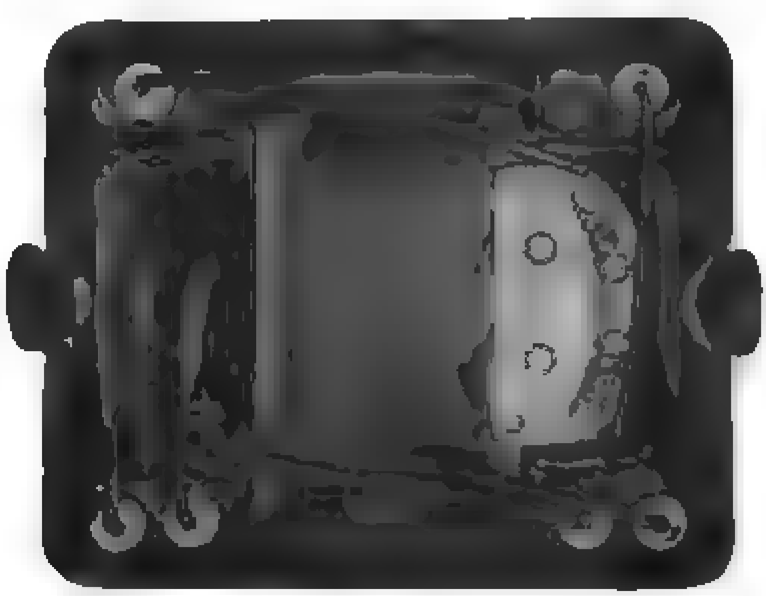


FIG. 1,943.—Top view of Fort Wayne (type A) transformer cover removed, showing assembly of coils and core and disposition of leads.

Ques. How is this loss reduced to a minimum?

Ans. By the usual method of laminating the core.

The iron core is built up of very thin sheet iron or steel stampings, and these are insulated from each other by varnish and are laid face to face at right angles to the path that the eddy currents tend to follow, so that the currents would have to pass from sheet to sheet, through the insulation.

Ques. In practice, upon what does the thickness of the laminæ or stampings depend?

Ans. Upon the frequency.

The laminæ vary in thickness from about .014 to .025 inch, according as the frequency is respectively high or low.

FIG. 1,944.—General Electric 10 kva., (type H) transformer removed from tank. That part of the steel core composing the magnetic circuit outside of the winding is divided into four equal sections. Each section is located a sufficient distance from the winding so that all portions of the winding and core are equally exposed to the cooling action of the oil. On all except the very smallest sizes the winding is divided by channels and ducts through which a continual circulation of oil is maintained. The result is uniform temperature throughout the transformer, thus eliminating the detrimental effects of unequal expansion in the coils with consequent rubbing and abrasion of the insulation.

Ques. Does a transformer take any current when the secondary circuit is open?

Ans. Yes, a "no load" current passes through the primary.

Ques. Why?

Ans. The energy thus supplied balances the core losses.

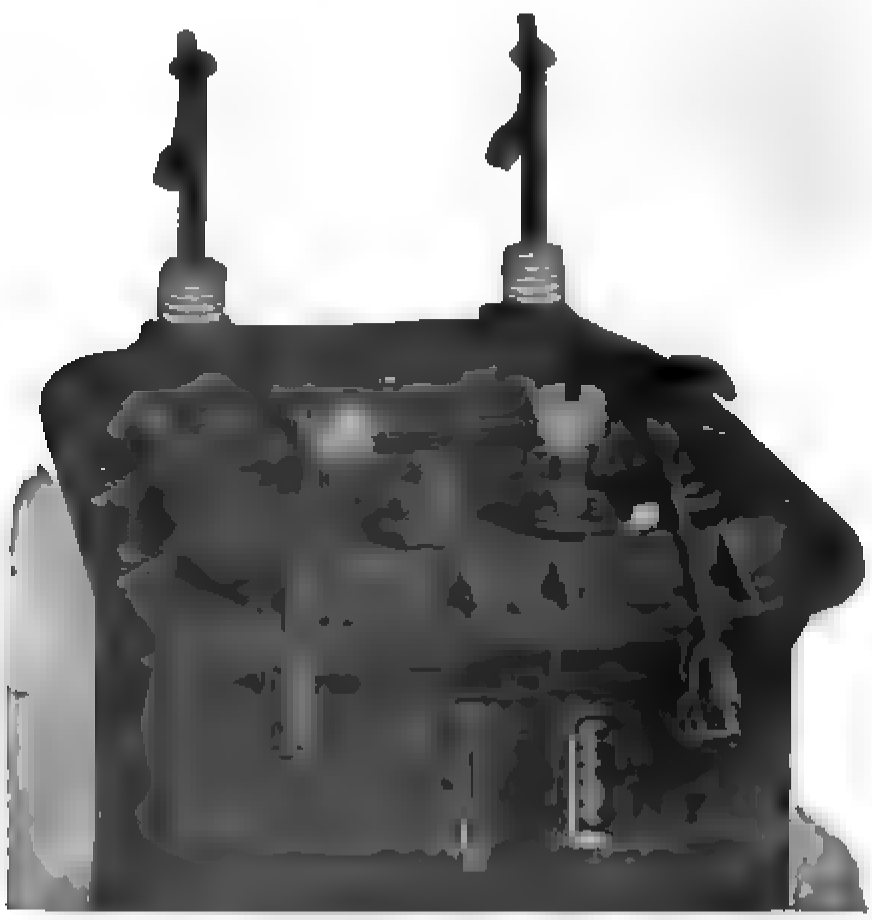
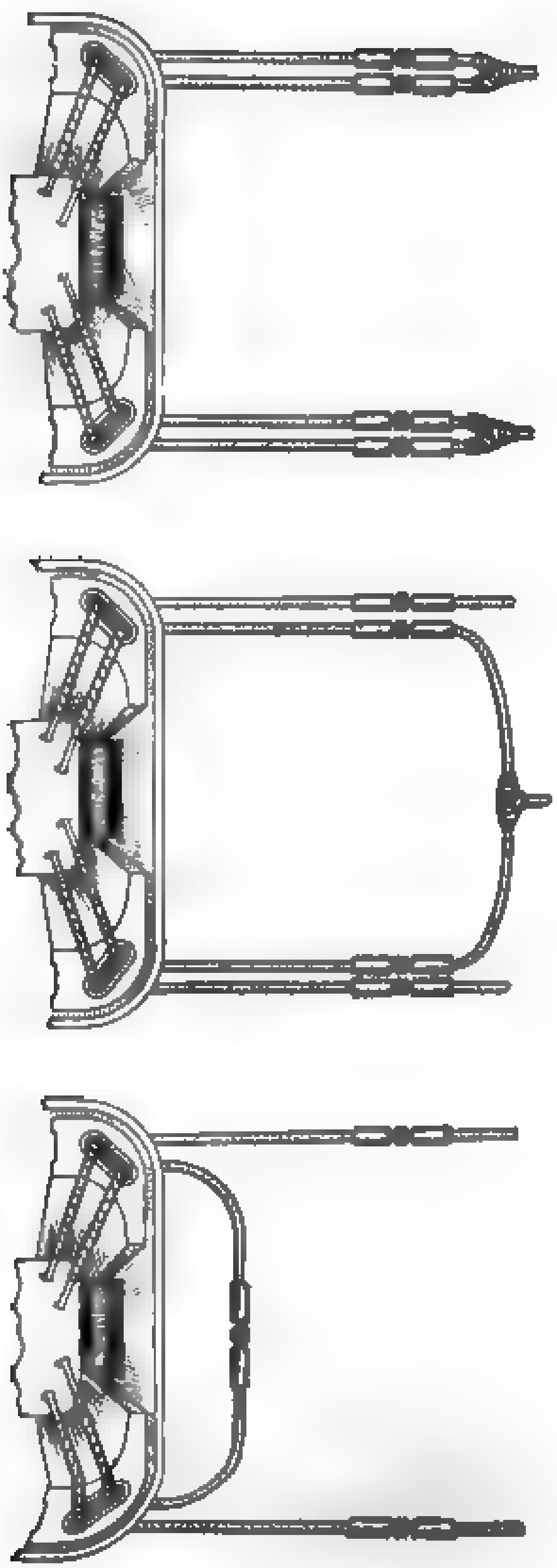


FIG. 1,945.—Cover construction of Wagner 350 kva., oil filled 1,100-2,200 volt transformer. In transformers with corrugated cases, the base and top ring are cast to the corrugated iron sheets.

Ques. Are the iron or copper losses the more important, and why?

Ans. The iron losses, because these are going on as long as *the primary* pressure is maintained, and the copper losses take *place only* while energy is being delivered from the secondary.



FIGS. 1,946 to 1,948.—Methods of connecting the low tension sides of Westinghouse transformers using the connectors illustrated in figs. 1,949 to 1,953.

Strictly speaking, on *no load* (that is when the secondary circuit is open) a slight copper loss takes place in the primary coil but because of its smallness is not mentioned. It is, to be exact, included in the expression "iron losses," as the precise meaning of this term signifies *not only the hysteresis and eddy current losses but the copper loss in the primary coil when the secondary is open.*

The importance of the iron losses is apparent in noting that in electric lighting the lights are in use only a small fraction of the 24 hours, but the iron losses continue all the time, thus the greater part of each day energy must be supplied to each transformer by the power company to meet the losses, during which time no money is received from the customers.

Some companies make a minimum charge per month whether any current is used or not to offset the no load transformer losses and rent of meter.

Ques. How may the iron losses be reduced to a minimum?

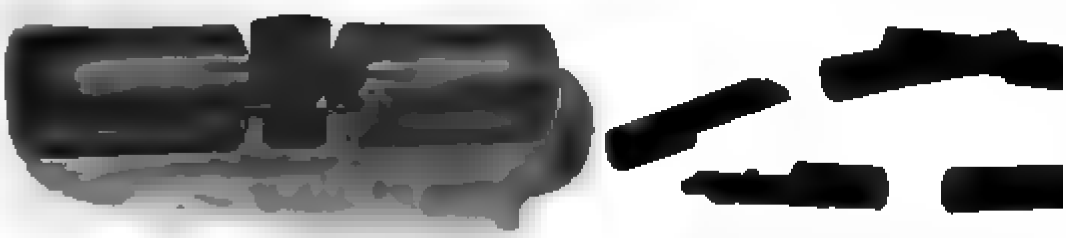
Ans. By having short magnetic paths of large area and using iron or steel of high permeability. The design and construction must keep the eddy currents as low as possible.

As before stated the iron losses take place continually, and transformers are loaded only a small fraction of a day it is ver that the iron losses should be reduced to a minimum.

With a large number of transformers on a line, the magn rent that is wasted, is considerable.

During May, 1910, the U. S. Bureau of Standards issue showing that each watt saving in core losses was a saving c which is evident economy in the use of high grade transform

Copper Losses.—Since the primary and secondary of a transformer have resistance, some of the energy will be lost by heating the copper. The amount of th proportional to square of the current, and is usually s as the I^2R loss.



FIGS. 1,949 to 1,953.—Westinghouse low tension transformer connectors for co low tension leads to the feeder wires. The transformers of the smaller ca knuckle joint connectors and those of the larger sizes have interleaved conne connectors form a mechanically strong joint of high current carrying capacity high tension leads are connected directly to the cut out or fuse blocks, conne required on these leads. The use of these connectors allows a transformer to and another of the same or a different capacity substituted usually without unsoldering a joint. The connectors also facilitate changes in the low tension

Ques. Define the copper losses.

Ans. The copper losses are the sum of the I^2R losses the primary and secondary windings, and the eddy cur in the conductors.

Ques. Is the eddy current loss in the conductor

Ans. No, it is very small and may be disregarded, the sum of the I^2R losses of primary and secondary can as the total copper loss for practical purposes.

Ques. What effect has the power factor on the copper losses?

Ans. Since the copper loss depends upon the current in the primary and secondary windings, it requires a larger current when the power factor is low than when high, hence the copper losses increase with a lowering of the power factor.

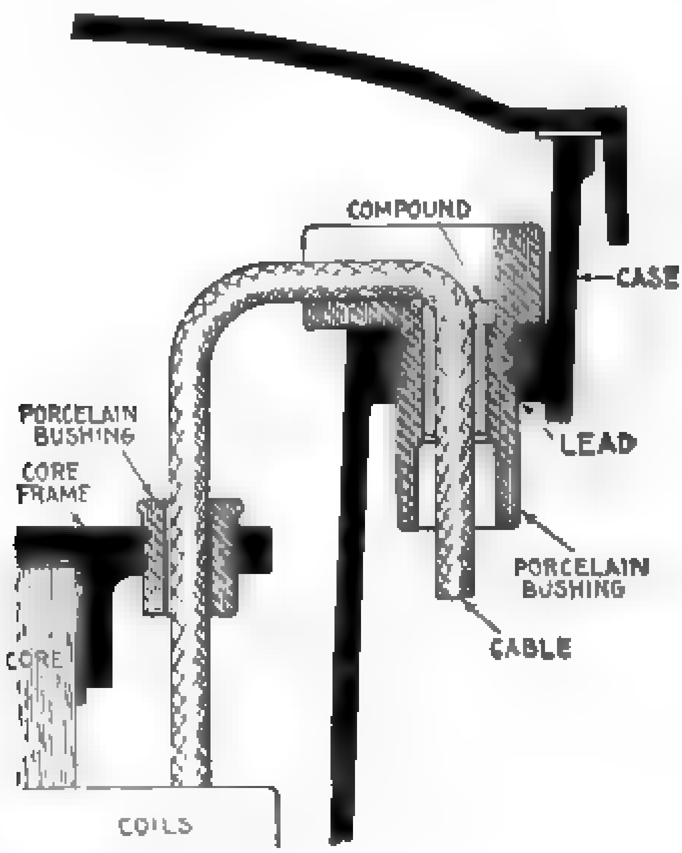


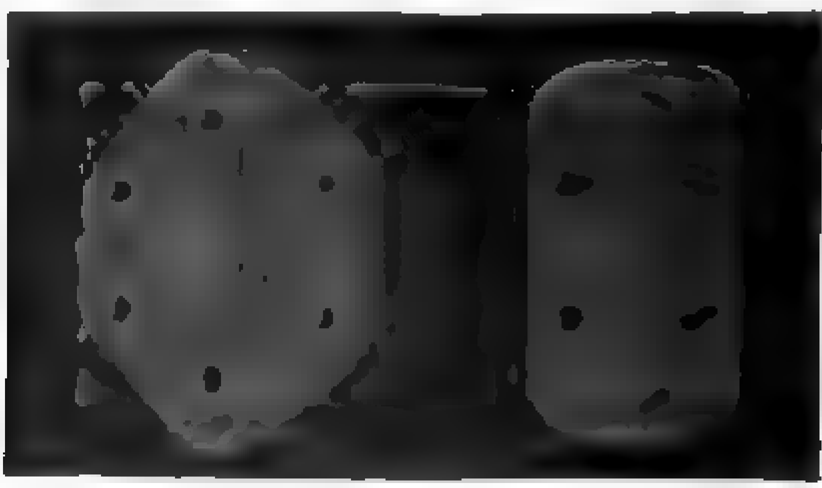
FIG. 1,954.—Method of bringing out the secondary leads in Wagner central station transformers. Each primary lead is brought into the case through a similar bushing. Observe the elimination of all possibility of grounding the cable on the case or core.

Ques. What effect other than heating has resistance in the windings?

Ans. It causes poor regulation.

This is objectionable, especially when incandescent lights are in use, because the voltage fluctuates inversely with load changes, that is, it drops as lamps are turned on and rises as they are turned off, producing disagreeable changes in the brilliancy of the lamps.

Cooling of Transformers.—Owing to the fact that a transformer is a stationary piece of apparatus, not receiving ventilation from moving parts, its efficient cooling becomes a very strong feature of the design, especially in the case of large high pressure transformers. The effective cooling is rendered more difficult because transformers are invariably enclosed in more or less air tight cases, except in very dry situations, where a perforated metal covering may be permitted.



FIGS. 1,955 and 1,956.—Westinghouse transformer terminal blocks for high and low tension conductors.

The final degree to which the temperature rises after continuous working for some hours, depends on the total losses in iron and copper, on the total radiating surface, and on the facilities afforded for cooling.

There are various methods of cooling transformers, the cooling mediums employed being

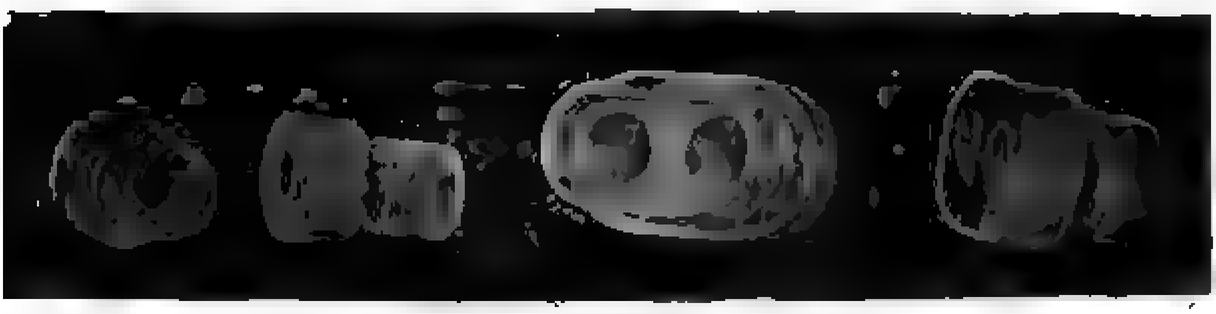
1. Air;
2. Oil;
3. Water.

The means adopted for getting rid of the heat which is inevitably developed in a transformer by the waste energy is one of the important considerations with respect to its design.

Ques. What is the behaviour of a transformer with respect to heating when operated continuously at full load?

Ans. The temperature gradually rises until at the end of some hours it becomes constant.

The difference between the constant temperature and that of the secondary atmosphere is called the temperature rise at full load. *Its amount constitutes a most important feature in the commercial value of the transformer.*



FIGS. 1,957 to 1,960.—Porcelain bushing for Westinghouse transformers.

Ques. Why is a high rise of temperature objectionable?

Ans. It causes rapid deterioration of the insulation, increased hysteresis losses, and greater fire risk.

Dry Transformers.—This classification is used to distinguish transformers using air as a cooling medium from those which employ a liquid such as water or oil to effect the cooling.

Air Cooled Transformers.—This name is given to all transformers which are cooled by currents of air without regard to the manner in which the air is circulated. There are two methods of circulating the air, as by

1. Natural draught;
2. Forced draught, or blast.

Ques. Describe a natural draught air cooled transformer.

Ans. In this type, the case containing the windings is open at the top and bottom. The column of air in the case expands as its temperature rises, becoming lighter than the cold air on the outside and is consequently displaced by the latter, resulting in a circulation of air through the case. The process is identical with furnace draught.

FIGS. 1,961 to 1,963.—Fuse blocks for Westinghouse transformers. The fuses furnished with the transformers are mounted in a weather proof porcelain fuse box of special design. The stationary contacts are deeply recessed in the porcelain and are well separated from each other. The contacts are so constructed that the plug is held securely in place by giving it a partial turn after inserting it. When the plug is in position, the fuse is in sight and its condition can be noted which eliminates all danger of pulling the fuse while same is still intact and the transformer is under load.

Ques. Describe a forced draught or air blast transformer.

Ans. The case is closed at the bottom and open at the top. A current of air is forced through from bottom to top as shown in fig. 1,964 by a fan.

Ques. How are the coils best adapted to air cooling?

Ans. They are built up high and thin, and assembled with *spaces between* them, for the circulation of the air.

Ques. What are the requirements with respect to the air supply in forced draught transformers?

Ans. Air blast transformers require a large volume of air at a comparatively low pressue. This varies from one-half to one ounce per square inch. The larger transformers require greater pressure to overcome the resistance of longer air ducts.

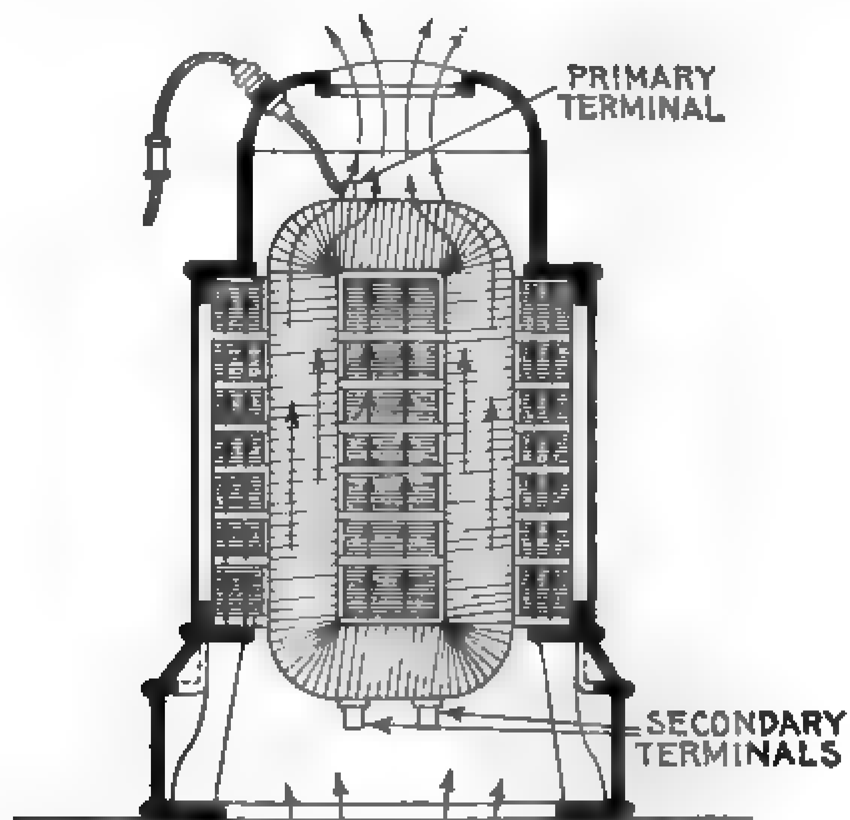


FIG. 1,964.—Forced draught or "air blast" transformer. As is indicated by the classification, this type of transformer is cooled by forcing a current of air through ducts, provided between the coils and between sectionalized portions of the core. The cold air is forced through the interior of the core containing the coils by a blower, the air passing vertically through the coils and out through the top. Part of the air is sometimes diverted horizontally through the ventilating ducts provided in the core, passing off at one side of the transformer. The amount of air going through the coils, or through the core, may be controlled independently by providing dampers in the passages.

Ques. How much air is used ordinarily for cooling per kw. of load?

Ans. About 150 cu. ft. of air per minute.

In forced draught transformers, the air pressure maintained by the blower varies from ½ to 1½ oz. per square inch. Forced draught or air blast transformers are seldom built in small sizes or for voltages higher than about 35,000 volts.

Oil Cooled Transformers.—In this type of transformer the coils and core are immersed in oil and provided with ducts to

FIG. 1965.—Looking down into a Wagner central station transformer, showing the connection board, which provides facility for varying the ratio of transformation and also for interchanging the primaries.

allow the oil to circulate by connection and thus serve as a medium to transmit the heat to the case, from which it passes by radiation.

Ques. Explain in detail the circulation of the oil.

Ans. The oil, heated by contact with the exposed surfaces *of the core* and coils, rises to the surface, flows outward and

descends along the sides of the transformer case, from the outer surface of which the heat is radiated into the air.

Ques. How may the efficiency of this method of cooling be increased?

Ans. By providing the case with external ribs or fins, or by "fluting" so as to increase the external cooling surface.

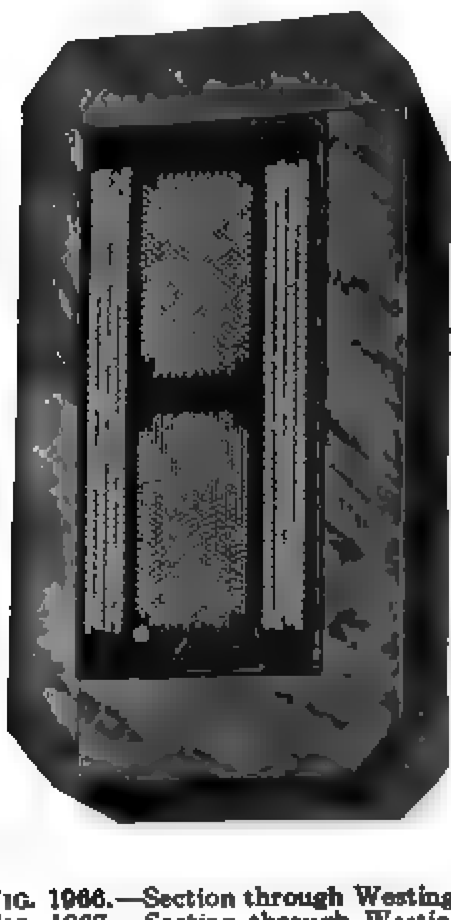


FIG. 1966.—Section through Westinghouse ½ kilovolt ampere type S transformer.
FIG. 1967.—Section through Westinghouse 50 kilovolt ampere type S transformer showing large oil ducts.

Ques. In what types of transformer is this mode of oil cooling used?

Ans. Lighting transformers.

In such transformers, the large volume of oil absorbs considerable heat, so that the rise of temperature is retarded. Hence, for moderate periods

of operation, say 3 or 4 hours, the average lighting period, the maximum temperature would not be reached.

Ques. In what other capacities except that of cooling agent, does the oil act?

Ans. It is a good insulator, preserves the insulation from oxidation, increasing the breakdown resistance of the insulation, and generally restores the insulation in case of puncture.

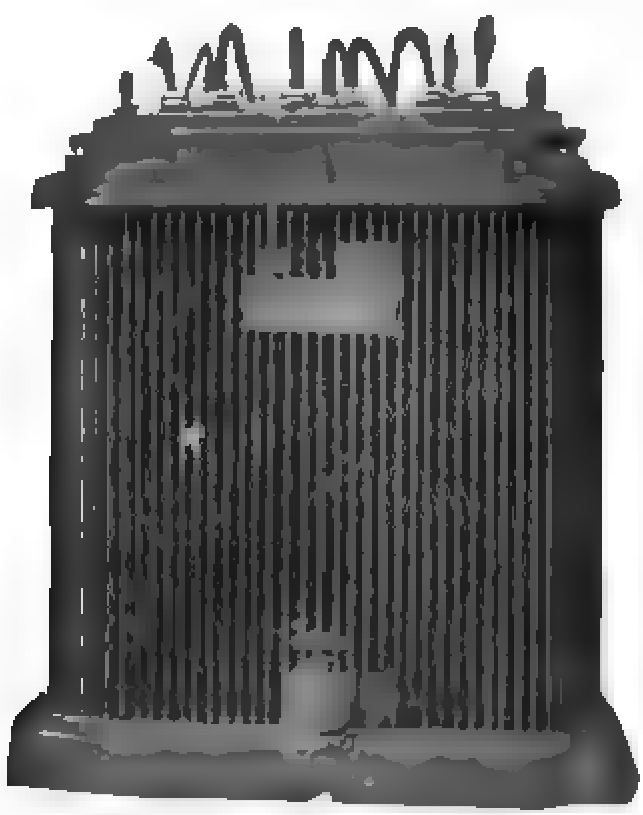


FIG. 1,968.—Wagner 300 kva, 4,400 volt three phase oil cooled transformer. In this type of transformer the case is filled with oil and fluted so as to increase the cooling surface, an oil drain valve is screwed to a wrought iron nipple cast into the base, the duct to which is in such a position as to make it possible not only to drain all of the oil from the transformer, but when desirable, to draw off a small quantity from the bottom. Should any moisture be in the oil it is therefore drawn off first.

Ques. What is the special objection to oil?

Ans. Danger of fire.

Ques. What kind of oil is used in transformers?

Ans. *Mineral oil.*

Ques. What are the requirements of a good grade of transformer oil?

Ans. It should show very little evaporation at 212° Fahr., and should not give off gases at such a rate as to produce an explosive mixture with the air at a temperate below 356°. It should not contain moisture, acid, alkali or sulphur compounds.

FIG. 1,969.—Section through Fort Wayne (type A) transformer showing interior of case, core conductors, and insulation, also division of laminæ.

The presence of moisture can be detected by thrusting a red hot nail in the oil; if the oil "crackle," water is present. Moisture may be removed by raising the temperature slightly above the boiling point, 212° Fahr., but the time consumed (several days) is excessive.

Water Cooled Transformers.—A water cooled transformer is one in which water is the cooling agent, and, in most cases, oil is the medium by which heat is transferred from the coils to the water. In construction, pipes or a jacketed casing is provided through which the cooling water is passed by forced circulation, as shown in figs. 1,970 and 1,971.

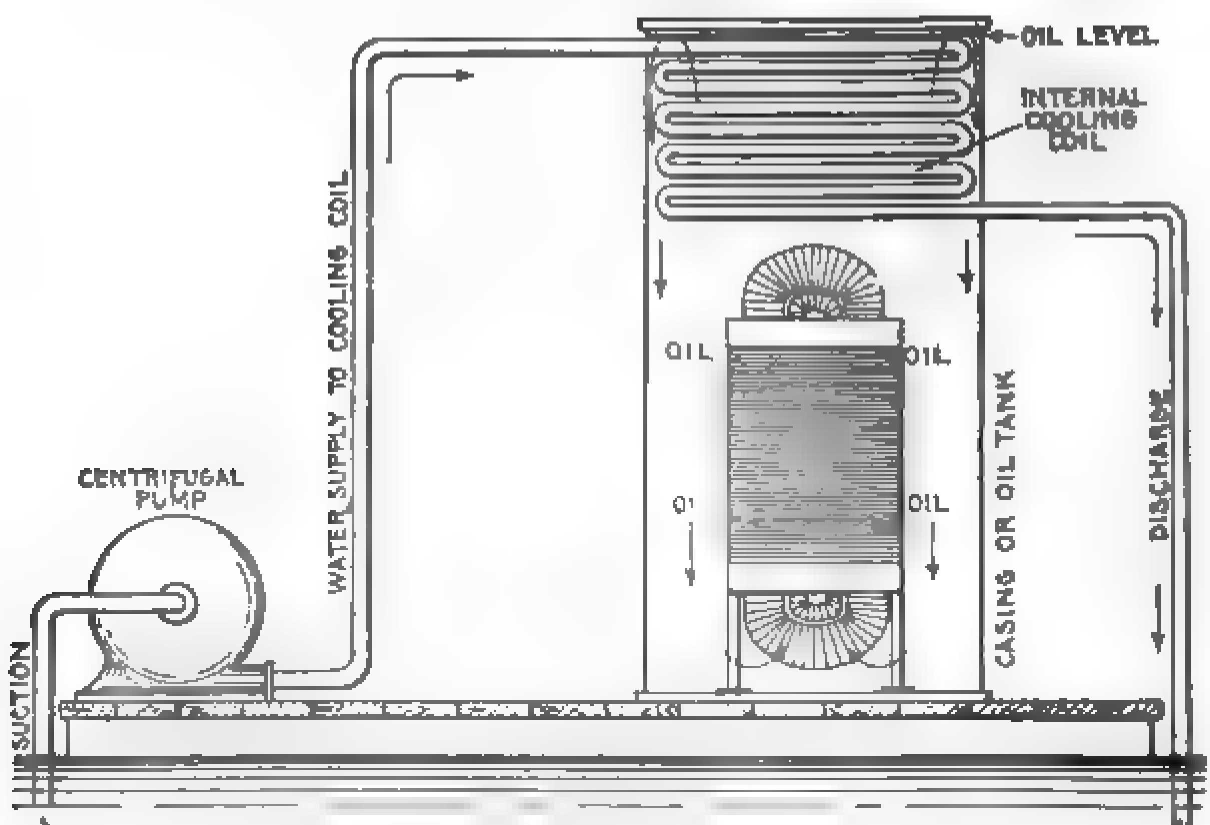


FIG. 1,970.—Water cooled transformer with internal cooling coil, that is, with cooling coil within the transformer case In this type, the cooling coil, through which the circulating water passes, is placed in the top of the case or tank, the latter is filled with oil so that the coil is submerged The oil acts simply as a medium to transfer the heat generated by the transformer to the water circulating through cooling coil. In operation a continual circulation of the oil takes place, as indicated by the arrows, due to the alternate heating and cooling it receives as it flows past the transformer coils and cooling coil respectively.

In some cases tubular conductors are provided for the circulation of the water.

Water cooled transformers may be divided into two classes, *as those having:*

1. Internal cooling coils;
2. External cooling coils.

Ques. Describe the first named type.

Ans. Inside the transformer case near the top is placed a coil of wrought iron pipe, through which the cooling water is

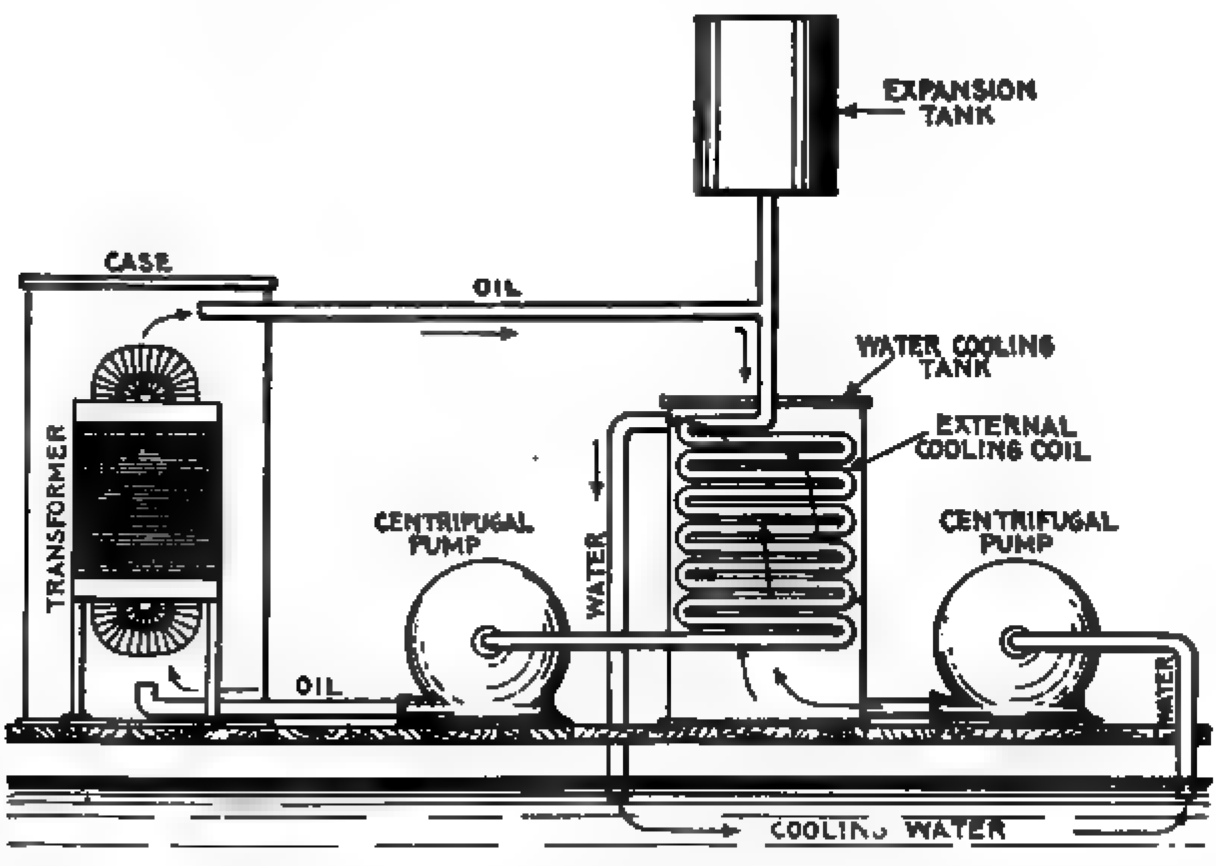


FIG. 1,971.—Water cooled transformer with external cooling coil. In this arrangement the cooling coil is placed in a separate tank as shown. Here forced circulation is employed for both the heat transfer medium (oil) and the cooling agent (water), two pumps being necessary. The cool oil enters the transformer case at the lowest point and absorbing heat from the transformer coils it passes off through the top connection leading to the cooling coil and expansion tank. Since the transformer tank is closed, an expansion tank is provided to allow for expansion of the oil due to heating. The water circulation is arranged as illustrated.

pumped. The case is filled with oil, which by *thermo-circulation* flows upward through the coils, transferring the heat absorbed from the coils to the water; on cooling it becomes more dense (heavier) and descends along the inside surface of the casing.

Ques. How much circulating water is required?

Ans. It depends upon the difference between the initial a discharge temperatures of the circulating water.

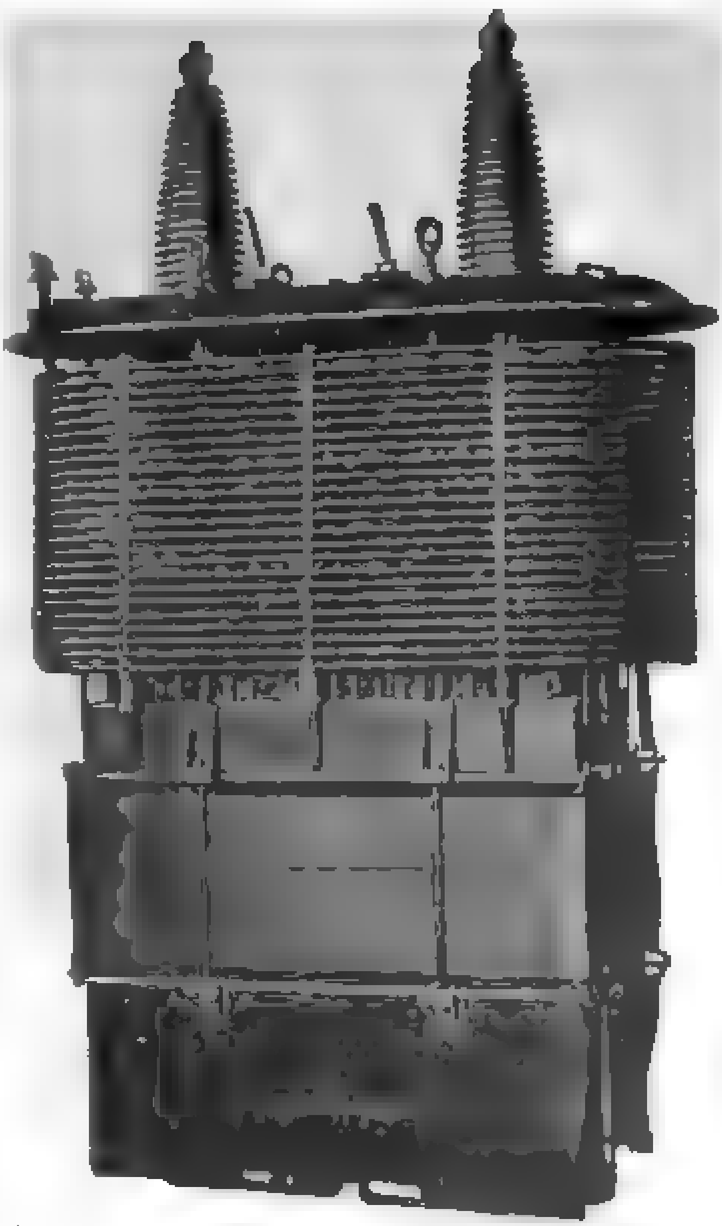


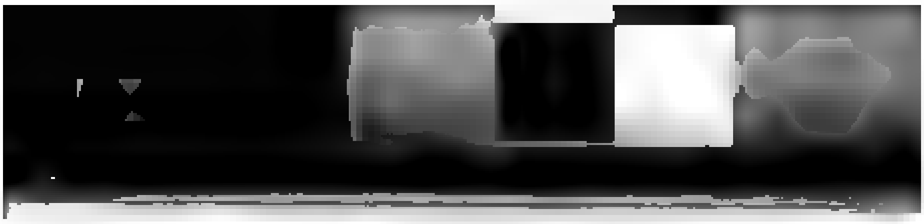
FIG. 1,972.—Interior of General Electric water cooled 140,000 volt transformer showing cooling coil.

Ques. In wat cooled transform how much cooli surface is requir for an internal co ing coil?

Ans. The surface the cooling coil shou be from .5 to 1.3 s in. per watt of to transformer loss, depen ing upon the amount heat which the extern surface of the tran former case will di sipate.

For a water temp ature rise of 43° Fah 1.32 lbs. of water p minute is required p kw. of load.

Transformer Insu lation.—This subje has not, until the la few years, been given the same special attention that man other electrical problems have received, although the developme



of the transformer from its original form, consisting of an iron core enclosed by coils of wire, to its present degree of refinement and economy of material, has been comparatively rapid.

In transformer construction it is obviously very important that the insulation be of the best quality to prevent burn outs and interruptions of service.

Ques. What is the "major" insulation?

Ans. The insulation placed between the core and secondary (low pressure) coils, and between the primary and secondary coils.

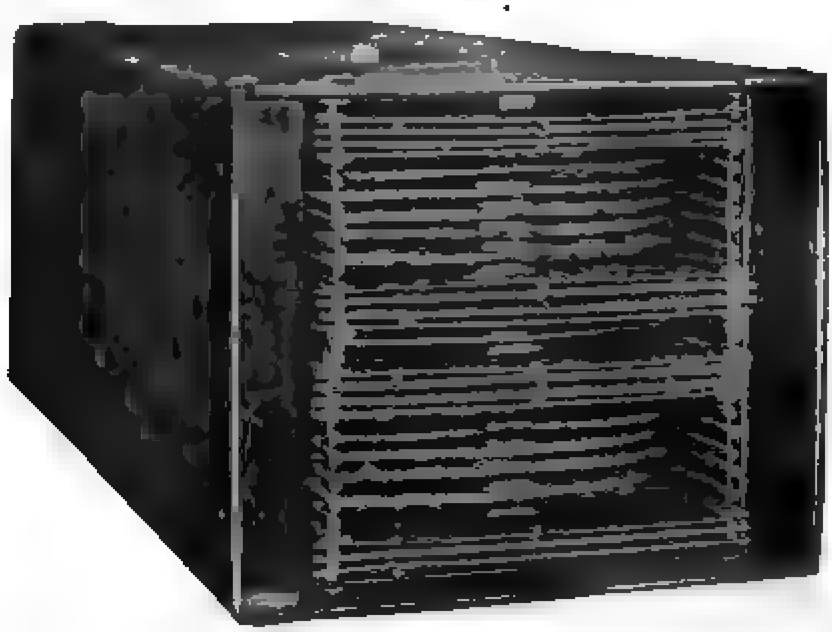


FIG. 1,973.—Assembled coils of General Electric water cooled 500 kva., 66,000 volt transformer.

It consists usually of mica tubes, sometimes applied as sheets held in place by the windings, when no ventilating ducts are provided, or moulded to correct form and held between sheets of tough insulating material where ducts are provided for air or oil circulation.

Ques. Describe the "minor" insulation.

Ans. It is the insulation placed between adjacent turns of the coils.

Since the difference of pressure is small between the adjacent turns the insulation need not be very thick. It usually consists of a double

thickness of cotton wrapped around each conductor. For round conductors, the ordinary double covered magnet wire is satisfactory.

Ques. What is the most efficient insulating material for transformers?

Ans. Mica.

FIG. 1,974.—Three Westinghouse 20 kva, outdoor transformers, for irrigation service. These are mounted on a drag so that they may be readily transported from place to place. 33,000 volts high tension; 2,200 and 440 volts low tension, 60 cycles. These outdoor transformers are of the oil immersed, self-cooling type and have been developed to meet the requirements for transformers of capacities greater or of voltages higher than are usually found in distribution work. They are in reality distributing transformers for high voltage, outdoor installations, single or three phase service, for voltages up to 110,000. Where the magnitude of the load does not warrant an expensive installation, transformers of the outdoor type are particularly applicable. The cost of a building and outlet bushings which is often the item of greatest expense is eliminated where outdoor type transformers are installed.

It has a high dielective strength, is fireproof, and is the most desirable insulator where there are no sharp corners.

Oil Insulated Transformers.—High voltage transformers are insulated with oil, as it is very important to maintain careful insulation not only between the coils, but also between the coils and the core. In the case of high voltage transformers, any accidental static discharge, such as that due to lighting, which might destroy one of the air insulated type, might be successfully withstood by one insulated with oil, for if the oil insulation be damaged it will mend itself at once.

By providing good circulation for the oil, the transformer can get rid of the heat produced in it readily and operate at a low temperature, which not only increases its life but cuts down the electric resistance of the copper conductors and therefore the $I^2 R$ loss.

Efficiency of Transformers.—The efficiency of transformers is *the ratio of the electric power delivered at the secondary terminals to the electric power absorbed at the primary terminals.*

Accordingly, the output must equal the input minus the losses. If the iron and copper losses at a given load be known, their values and consequently the efficiency at other loads may be readily calculated.

EXAMPLE.—If a 10 kilowatt constant pressure transformer at full load and temperature have a copper loss of .16 kilowatt, or 1.6 per cent., and the iron loss be the same, then its

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{10}{10 + .16 + .16} \times 100 = 96.9 \text{ per cent}$$

At three-quarters load the output will be 7.5 kilowatts; and as the iron loss is practically constant at all loads and the copper loss is proportional to the square of the load, the

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{7.5}{7.5 + .16 + .09} \times 100 = 96.8 \text{ per cent.}$$

The matter of efficiency is important, especially in the cas large transformers, as a low efficiency not only means a l waste of power in the form of heat, but also a great increas the difficulties encountered in keeping the apparatus c The efficiency curve shown in fig. 1,975, serves to indicate, h ever, how slight a margin actually remains for improvement this particular in the design and construction of large transform

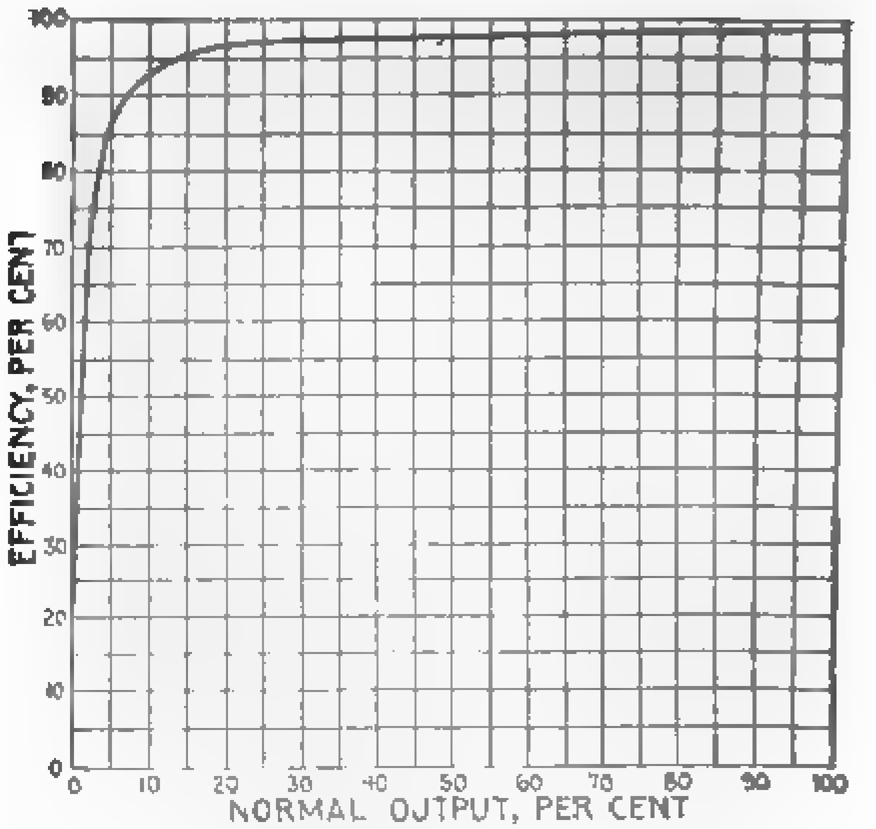


FIG. 1,975.—Efficiency curve of Westinghouse 375 kw. transformer. Pressure 500 to 1 volts; frequency 60. Efficiencies at different loads: full load efficiency, 98%; ¾ load efficiency, 98%; ½ full load efficiency, 97.6%; ¼ full load efficiency 96.1%; e tion non-inductive load, 1.4%, load having .9 power factor, 3.3%.

The efficiency of transformers is, in general, higher than that of o electrical machines; even in quite small sizes it reaches over 90 per c and in the largest, is frequently as high as 98.5 per cent.

To measure the efficiency of a transformer directly, by measu input and output, does not constitute a satisfactory method when efficiency is so high. A very accurate result can be obtained, howe *by measuring* separately, by wattmeter, the core and copper losses.

The core loss is measured by placing a wattmeter in circuit wh *transformer* is on circuit at no load and normal frequency.

The copper loss is measured by placing a wattmeter in circuit with the primary when the secondary is short circuited, and when enough pressure is applied to cause full load current to flow.

If it be desired to separate the load losses from the true I^2R loss, the resistances can be measured, and the I^2R loss calculated and subtracted from the wattmeter reading. The losses being known, the efficiency at any load is readily found by taking the core loss as constant and the copper loss as varying proportionally to the square of the load. Thus,

$$\text{efficiency} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100$$

All Day Efficiency of Transformers.—This denotes the ratio of the total watt hour output of a transformer to the total watt hour input taken over a working day. To compute this efficiency it is necessary to know the load curve of the transformer over a day. Suppose that this is equivalent to 5 hours at full load, and 19 hours at no load. Then, if W_1 be the core loss in watts, W_2 the copper loss at rated load, and W the rated output,

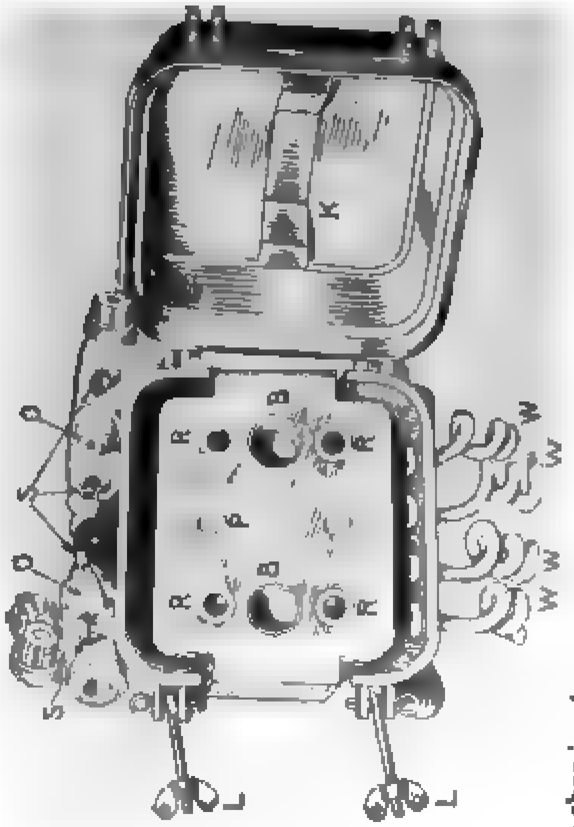
$$\begin{aligned} \text{output} &= 5 \times W, \\ \text{losses} &= 5\,(W_1 + W_2) + 19\,W_1, \\ \text{input} &= 5\,(W + W_1 + W_2) + 19\,W_1, \end{aligned}$$

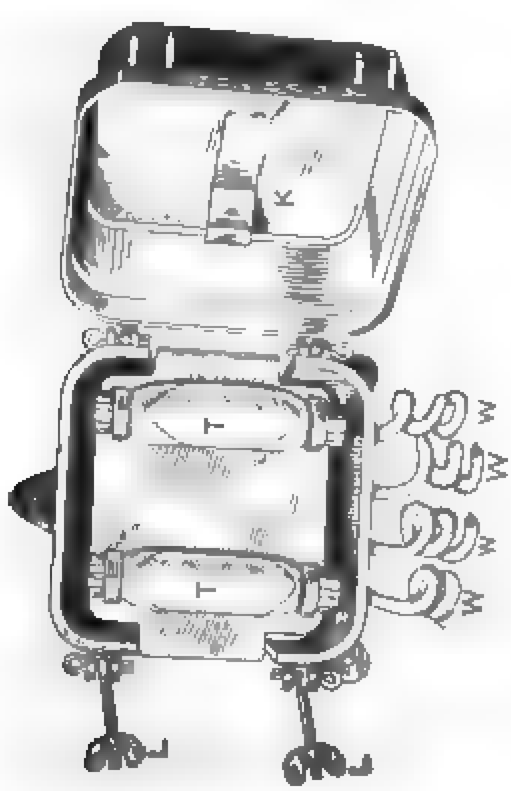
and the all day efficiency is equal to

$$\frac{5\,W \times 100}{5\,(W + W_1 + W_2) + 19\,W_1}\ \text{per cent.}$$

Commercial or all day efficiency is a most important point in a good transformer. The principal factor in securing a high all day efficiency is to keep the core loss as low as possible. The core loss is constant—it continues while current is supplied to the primary, while copper loss takes place only when the secondary is delivering energy.

In general, if a transformer is to be operated at light loads the greater part of the day, it is much more economical to use *one designed for a small iron loss than for a small full load copper loss.*





FIGS. 1,976 and 1,977.—Westinghouse double pole fuse box; views showing box open with tubes in place, and with tubes removed.

Transformer Fu Blocks.—These may be either the single pole or doul pole type. Fig. 1,976 show double pole fuse box opene and fig. 1,977, the fuse b opened and the tubes r moved. Of the four wire W, W, W, W, entering th box from beneath, two a from the primary mains, an two lead to the primary co of the transformer. Thes wires terminate in metalli receptacles R, R, R, R, in th porcelain plate P, fig. 1,977 which are bridged over in pairs by fuse wires placed inside porcelain tubes T, T, as shown in fig. 1,976. These tubes are air tight except for a small outlet O in each, which fit into the receptacles B, B, in the porcelain plate and open out at the back of the block, as shown in fig. 1,977.

The fuse wires are connected between metallic spring tubes S, S, S, S, which fit into the receptacles R, R, R, R.

If a sudden load or a short circuit occur in the transformer, the intense heat,

accompanying the melting or blowing of the fuse, causes a rapid expansion of the air inside the tube, so that a strong blast of air rushes through the outlet O of the tube and immediately extinguishes the arc.

By this arrangement, sustained arcing is prevented, as the action of the tube causes the arc to extinguish itself automatically when the current is interrupted.

The porcelain tubes are held in position by the spring K, and the primary of the transformer becomes entirely disconnected from the circuit when the tubes are lifted out.

This form of construction enables the lineman to detach the tubes from the fuse box, and insert the fuse at his convenience. Furthermore,

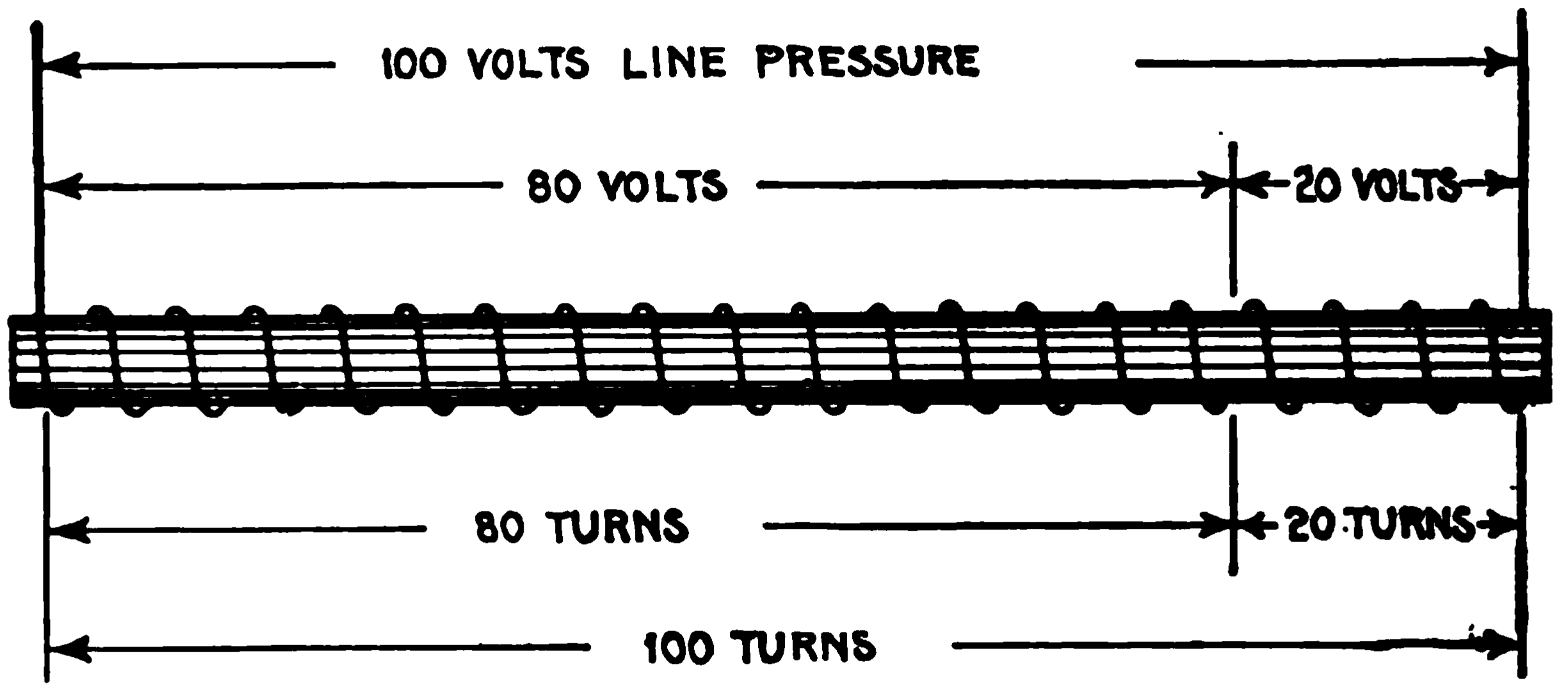


FIG. 1,978.—Diagram illustrating connections and principles of auto-transformers as explained in the accompanying text.

when inserting fuse in a short circuited line, he does not run the risk of being hurt, as the heated vapor of the exploding fuse can escape through the outlet provided for that purpose, and in a predetermined direction.

The method of attaching the lid not only permits of quick access to the interior of the box, but enables the lineman to tighten the joints by means of the thumb screws L, L, so as to keep the box waterproof.

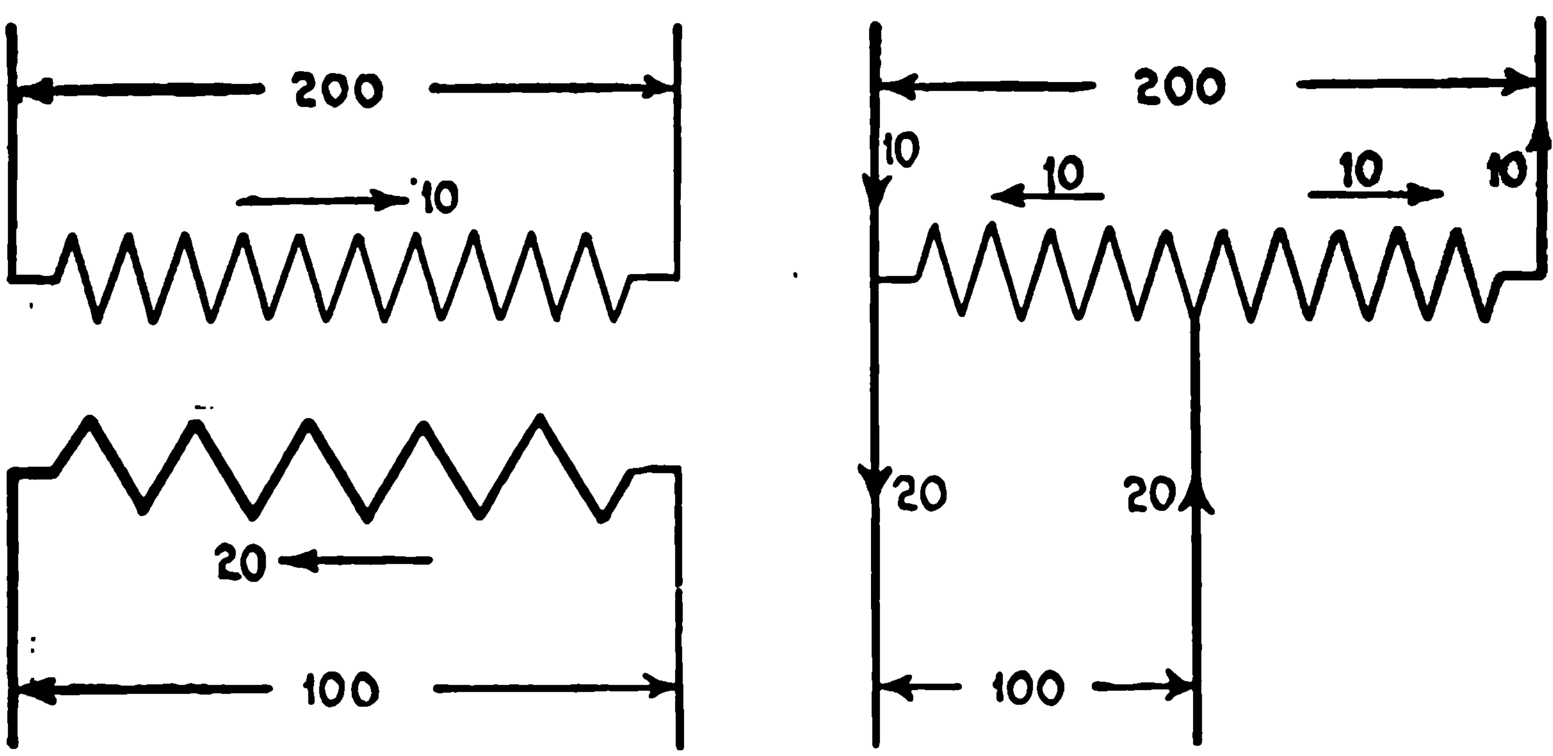
Auto-transformers.—In this class of transformer, there is only one winding which serves for both primary and secondary. On account of its simplicity it is made cheaply.

Auto-transformers are used where the ratio of transformation is small, as a considerable saving in copper and iron can be effected, and the whole transformer reduced in size as compared with one having separate windings.

Fig. 1,978 illustrates the electrical connections and the relations between the volts and number of turns.

By using the end wire and tapping in on turn No. 20 a current at 20 volts pressure is readily obtained which may be used for starting up motors requiring a large starting current and yet not draw heavily on the line.

Since the primary is connected directly to the secondary it would be dangerous to use an auto-transformer on high pressure circuits. This type of transformer has only a limited use, usually as compensator for motor starting boxes.



FIGS. 1,979 and 1,980.—Two winding transformer and single winding or auto-transformer. Fig. 1,979 shows a 200:100 volt transformer having a 10 amp. primary and a 20 amp. secondary, the currents being in opposite directions. If these currents be superposed by using one winding only, the auto-transformer shown in fig. 1,980 is obtained where the winding carries 10 amp. only and requires only one-half the copper (assuming the same mean length of turn). If R be the ratio of an auto-transformer, the relative size of it compared with a transformer of the same ratio and output is as $\frac{R-1}{R}$: 1. For example, a 10 kw. transformer of 400 volts primary and 300 volts secondary could be replaced by an auto-transformer of $10 \times \frac{1.33-1}{1.33} = 2.5$ kw.; or, in other words, the amount of material used in a 2½ kw. transformer could be used to wind an auto-transformer of 400 : 300 ratio and 10 kw. output.

Constant Current Transformers for Series Arc Lighting.—The principle of the constant current transformer as *used for series* arc lighting is readily understood by reference

to the elementary diagram shown in fig. 1,981. A constant alternating current is supplied to the stationary primary coil which induces a current in the movable secondary coil. The pressure induced in the coil will depend on the number of lines of flux which pass through it and by changing its position in the magnetic field over the primary a variable e.m.f. can be produced and a constant current maintained in the lighting circuit when the lamps are turned on or off, or if the resistance of the circuit be lowered by the consumption of the carbons.

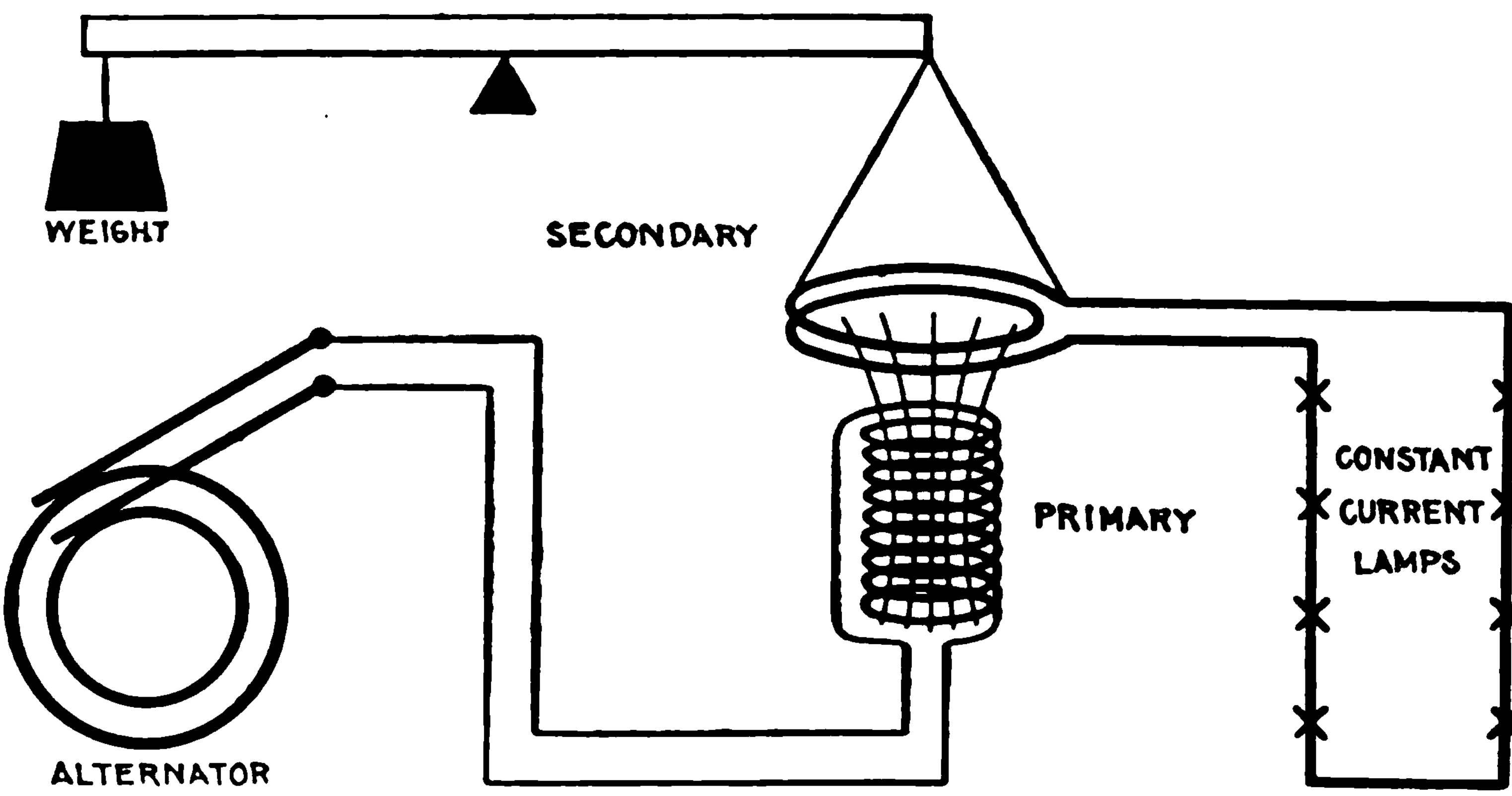


FIG. 1,981.—Elementary diagram illustrating the principles of constant current transformer as used for series arc lighting.

Since the induced currents in the secondary are repelled by the primary there is a tendency for the secondary coil to jump out of the primary field, and in case of a very large current due to a short circuit in the lamp circuit, the secondary current is quickly reduced to normal by the rapid movement of the coil upward.

By adjusting the counterweight for a given number of amperes required by the arc, the current will be maintained constant by the movement of the secondary coil.

The magnetic field produced by the primary must be k the same by a constant current from the alternator, theref when the lamp load is increased the primary voltage increa similar to that of an ordinary series wound direct curr dynamo. In other words the alternator and regulating tra former supply a constant current and variable voltage.

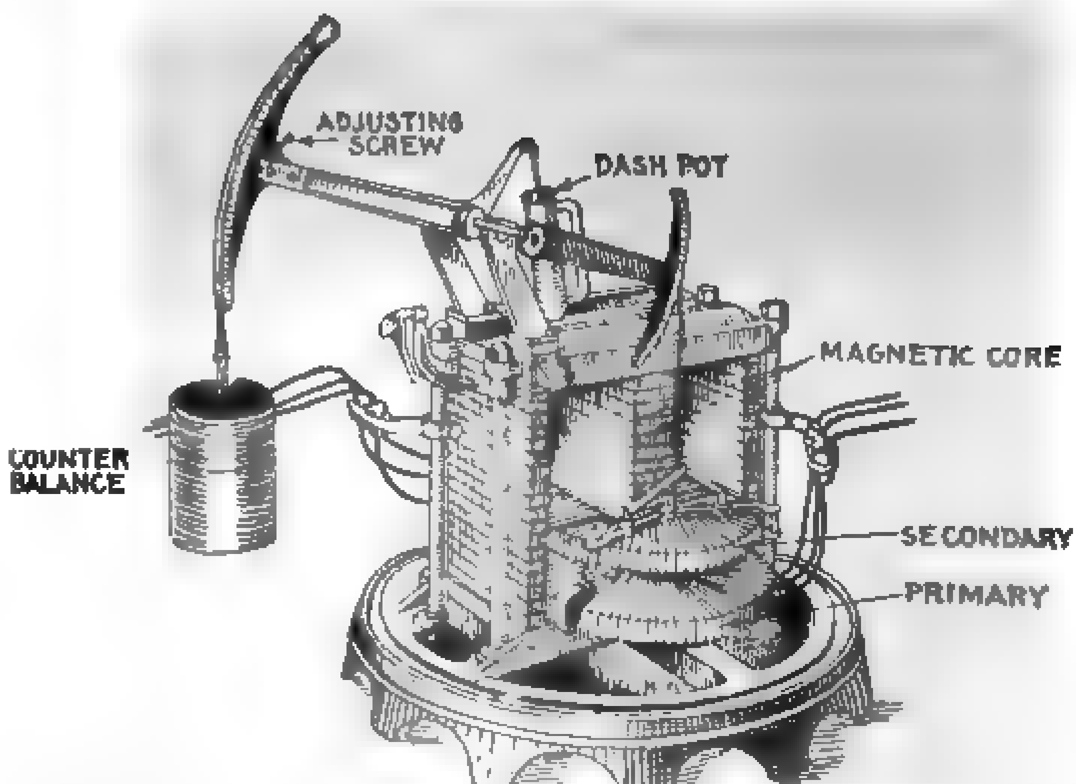


FIG. 1,982.—Mechanism of General Electric air cooled constant current transformer. operates on the principle explained in the accompanying text and is built to supply 2 100 arc lamps at 6.6 to 7.5 amperes. The transformers are interchangeable and operate on 60 or 125 cycles. The relative positions of the two coils may be changed in o to regulate the strength of the current more closely, by shifting the position of the carrying the counterbalance by means of the adjusting screw on it. A dash pot filled special oil prevents sudden movements of the secondary coil and keeps the current thro the lamps nearly constant, when they are being cut in or out of the circuit. In star up a constant current transformer, it is necessary to separate the two coils as far as sible and then close the primary circuit switch and allow the two coils to come toget If the primary circuit be thrown directly on the generator the heavy rush of current wl will follow due to the two coils being too close together might injure the lamps.

Constant current incandescent lighting systems for use small towns also use this method for automatically regulati the current.

Regulation.—This term applies to the means adopted either to obtain constancy of pressure or current. In the transformer, regulation is *inherent*, that is, the apparatus automatically effects its own regulation. The regulation of a transformer means, *the change of voltage due to change of load on the secondary*; it may be defined more precisely as: *the percentage increase in the secondary voltage as the load is decreased from its normal value*

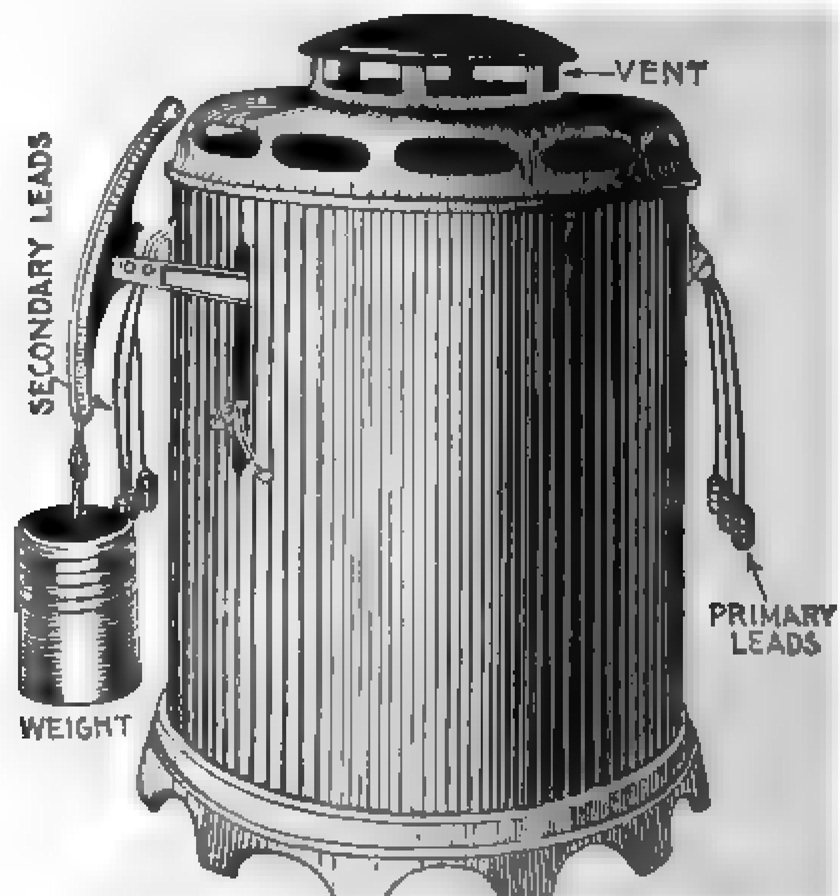
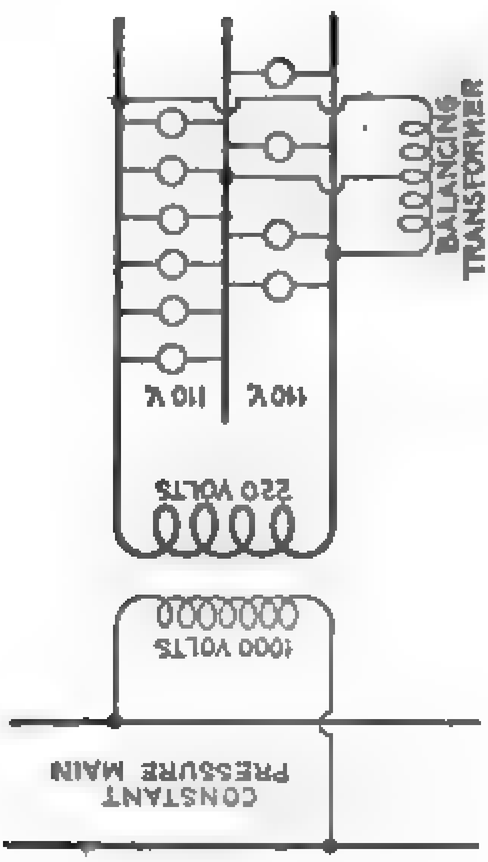


FIG. 1,983.—General Electric air cooled constant current transformer. View showing external appearance with case on.

to zero. Thus, observation should be made of the secondary voltage, at full load and at no load, the primary pressure being held constant at the normal value.

The regulation is said to be "good" or "close," when this change is small. In the design of a transformer, good regulation and low iron *losses* are in opposition to one another when the best results are desired in



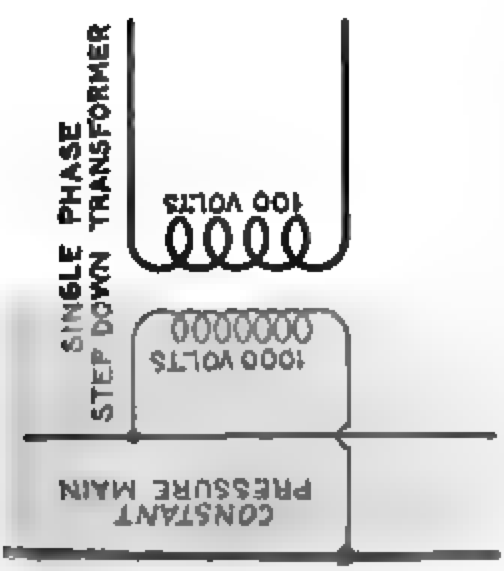


Fig. 1,984.—Single phase transformer connection with constant pressure main.
Fig. 1,985.—Usual method of single phase transformer connections for residence lighting with three wire secondaries. A balancing transformer is connected to the center of the three wire circuit near the center of distribution as shown.

both. A well designed transformer, however, should give good results, both as to regulation and iron losses, the relative value depending upon the class of work it has to do, and size.

Transformer Connections.—The alternating current has the advantage over direct current, in the ease with which the pressure and current can be changed by different connections of transformers.

On single phase circuits the transformer connections can be varied to change current and pressure, and in addition on polyphase circuits the phases can also be changed to almost any form.

Single Phase Connections.—The method of connecting ordinary distributing transformers to constant pressure mains is shown by the elementary diagram, fig. 1,984, where a transformer of 10 to 1 ratio is indicated with its primary winding connected to a 1,000 volt main, and a secondary winding to deliver 100 volts.

Fig. 1,986 shows a transformer with each winding divided into two sections. Each primary section is wound for 1,000 volts, and each secondary section for 50 volts. By connecting the entire primary winding in series, the transformer may be supplied from a 2,000 volt main, as indicated, and if the secondary winding be also connected all in series, as shown, the no load voltage will be 100 between the secondary terminals.

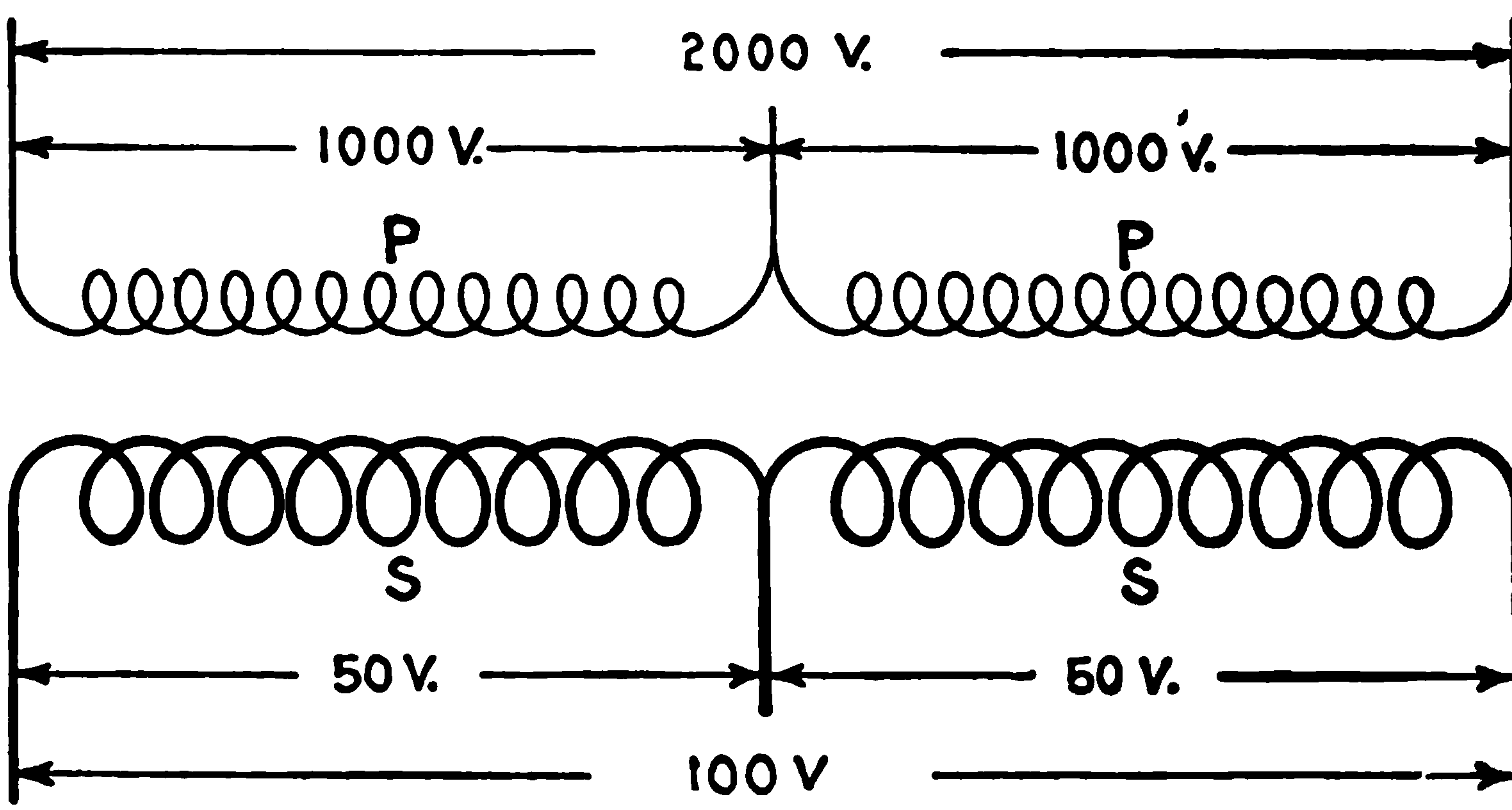


FIG. 1,986.—Diagram of single phase transformer having primary and secondary windings in two sections, showing voltages per section with series connections.

The sections of the primary winding may be connected in parallel to a 1,000 volt main, and 100 volts obtained from the secondary, or the primary and secondary windings may be connected each with its two sections in parallel, and transformations made from 1,000 to 50 volts as represented in fig. 1,987.

This is a very common method of construction for small transformers, which are provided with convenient terminal blocks for combining the sections of each winding to suit the requirements of the case. When the two sections of either winding are connected in parallel as shown in fig. 1,987, *care must be taken to connect corresponding ends of the two sections together.*

Combining Transformers.—Two or more transform built to operate at the same pressure and frequency may be nected together in a variety of ways; in fact, the primary secondary terminals may each be considered exactly as terminals of direct current dynamos, with certain restriction

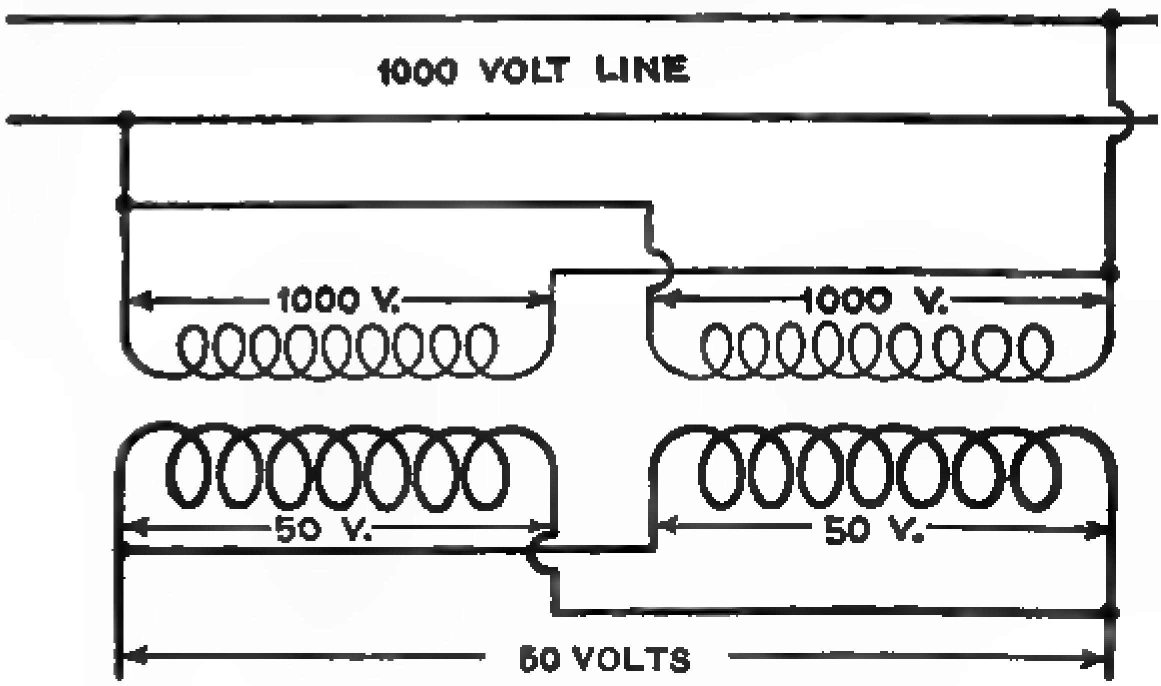


FIG. 1,987.—Diagram of single phase transformer with primary and secondary windings sections each, showing voltages per section with parallel connection.

Ques. What are the two principal precautions wh must be observed in combining transformer terminals

Ans. The terminals must have the same polarity at a gi instant, and the transformers should have practically ident characteristics.

The latter condition is not absolutely essential, but it is emphatic preferable. For example, if a transformer, which has 2 per cent. r lation, be connected in parallel, as indicated in fig. 1,988, with one wl has 3 per cent. regulation, at no load the transformers will give exa the same voltage at the secondary terminals, but at full load one have a secondary pressure of, say, 98 volts, while the other has 97 The result is that the transformer giving only 97 volts will be

to a reverse pressure of one volt from its mate. This will not cause excessive current to flow backward through the secondary winding of the low voltage transformer, but it will disturb the phase relations and lower the power factor and efficiency of the combination. In such a case it is much better to work the secondary circuits of the two transformers separately.

In case the transformers have practically the same characteristics it is necessary, as stated above, to make sure that the secondary terminals connected together have the same polarity at a given instant; it is not necessary to find out definitely what the polarity is, merely that it is the same for both terminals. This can be easily done as shown in fig. 1,989.

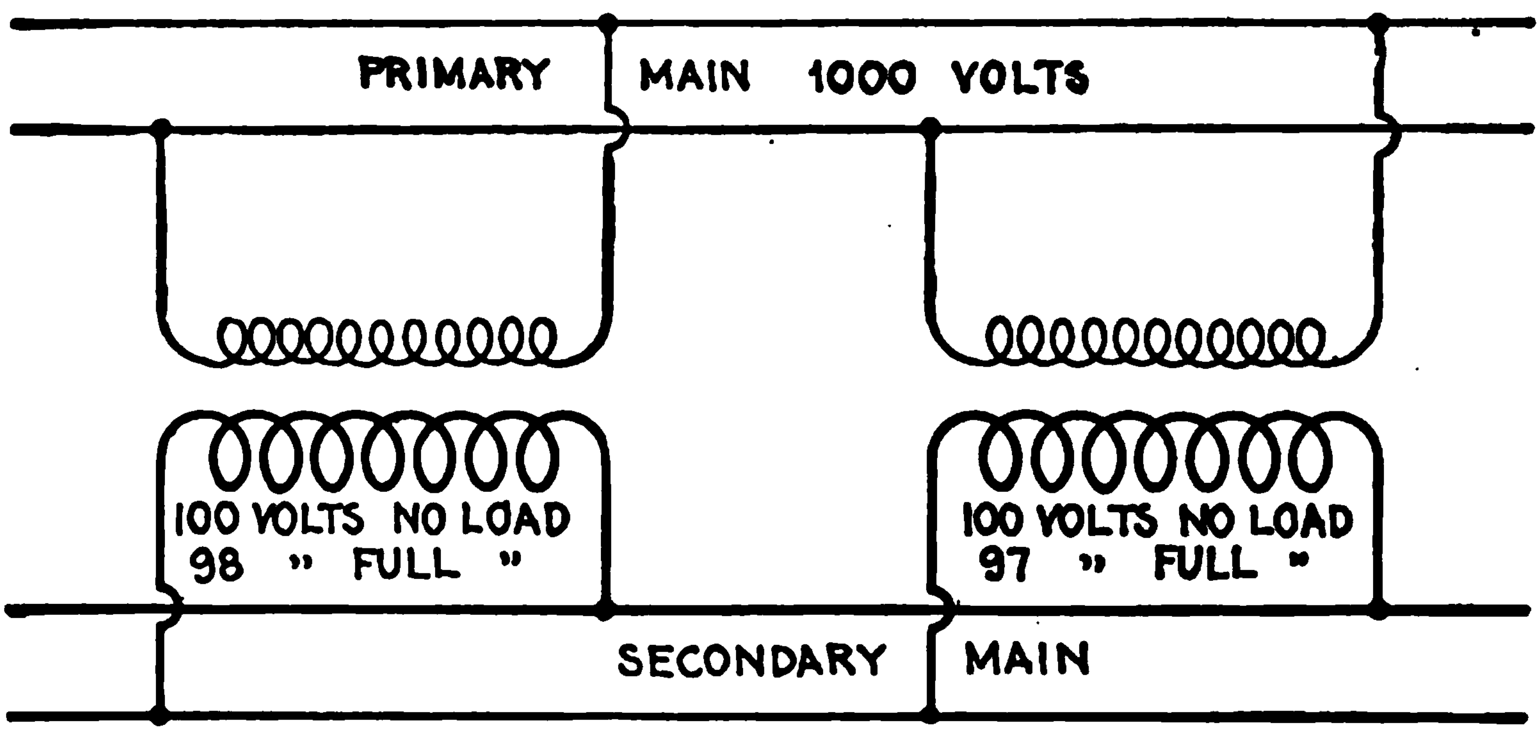


FIG. 1,988.—Diagram showing unlike single phase transformers in parallel.

Ques. What may be said with respect to operating transformer secondaries in parallel?

Ans. It is seldom advantageous. Occasionally it may be necessary as a temporary expedient, but where the load is such as to require a greater capacity than that of a transformer already installed, it is much better to replace it by a large transformer than to supplement it by an additional transformer of its own size.

Ques. How are the secondaries arranged in modern transformers and why?

Ans. The secondary windings are divided into at least two sections so that they may be connected either in series or parallel.

Ques. Explain how secondary connections are ma for different voltages.

Ans. If, for instance, the secondary pressure of a tra former having two sections be 100 volts with the terminals parallel, as in fig. 1,990, then connecting them in series will g 200 volts at the free secondary terminals, as indicated in fig. 1,9

Ques. What precaution should be taken in connecti secondary sections in parallel in core type if the t sections be wound on different limbs of the core?

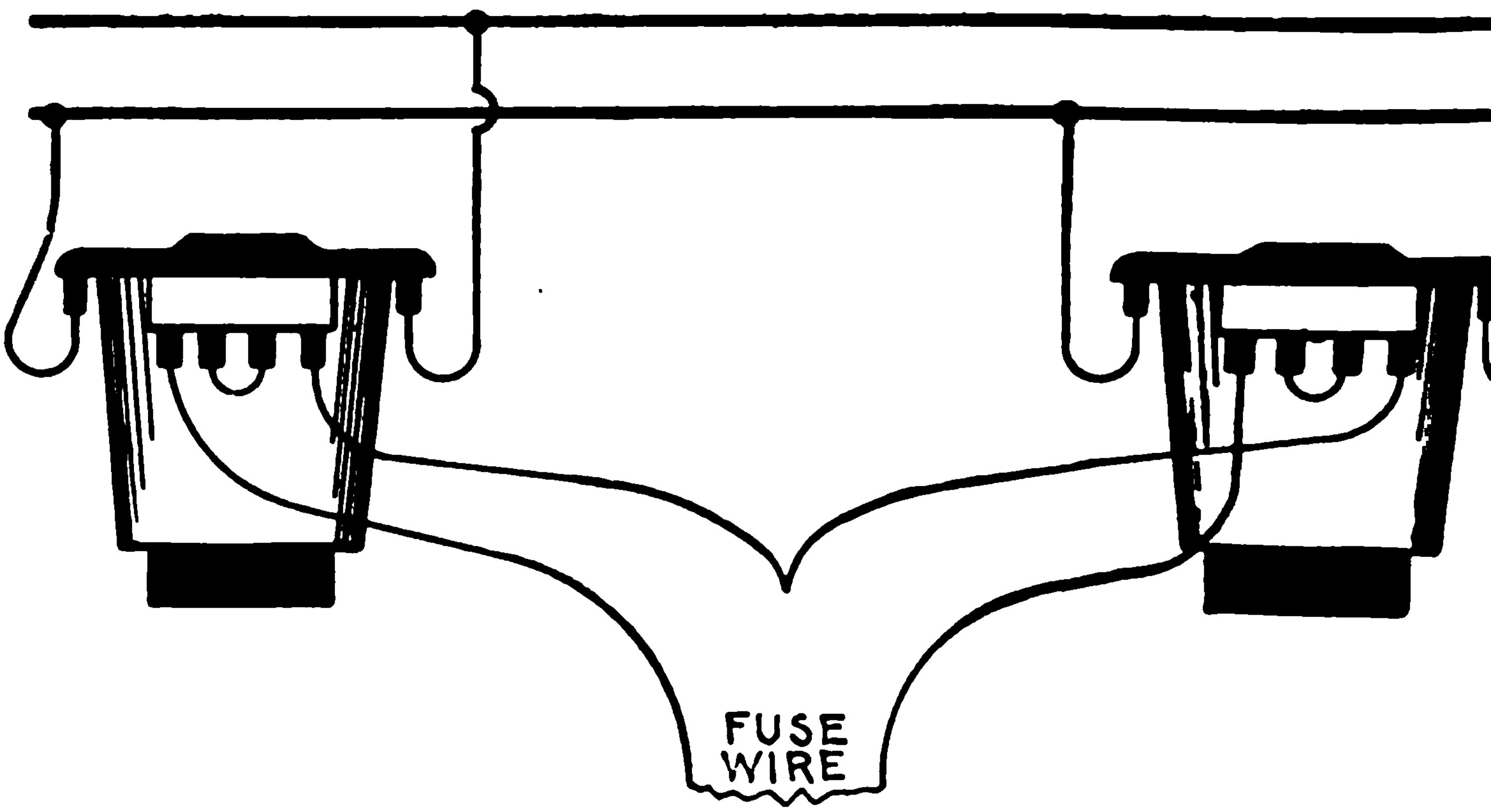
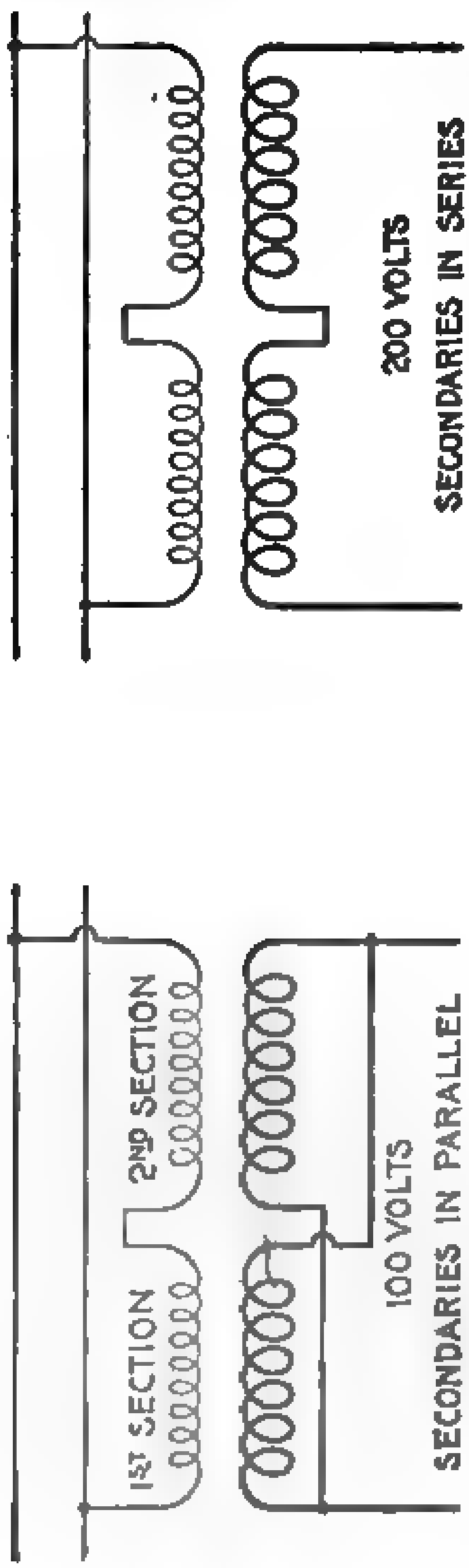


FIG. 1,989.—Method of comparing instantaneous polarity. Two of the terminals are c nected as shown by a small strip of fuse wire, and then touching the other two termin together. If the fuse blow, then the connections must be reversed; if it do not, t they may be made permanent.

Ans. It will be advisable to make the connections amp and permanent, so that there will not be any liability to difference between the current flowing in one secondary windi and that flowing through the other.

Two Phase Connections.—In the case of two phase di ribution each circuit may be treated as entirely independe the other so far as the transformers are concerned. Tw



Figs. 1,990 and 1,991.—Methods of altering the secondary connections of a transformer having two sections in the secondary to obtain a different voltage. Fig. 1,990 shows the two sections in parallel giving say 100 volts; fig. 1,991 shows the two sections in series giving 200 volts.

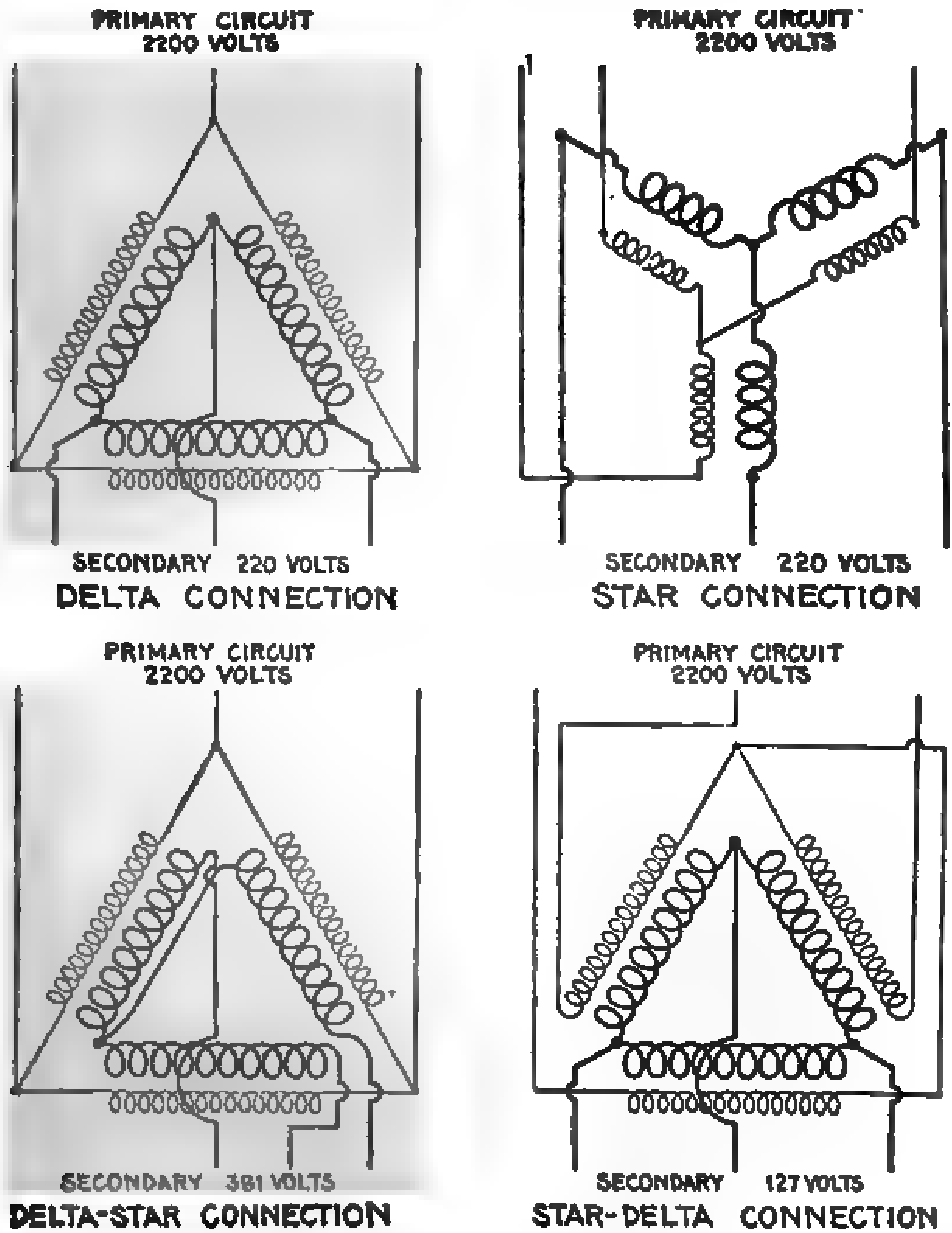
transformers are used, one being connected to one primary phase and supplying one secondary phase, the other being connected to the other primary phase and supplying the other secondary phase as indicated in fig. 1,996, exactly as though each primary and secondary phase were an ordinary single phase system, independent of the other phase.

Ques. Is the above method usually employed?

Ans. No, the method shown in fig. 1,997 is generally used.

Three Phase Connections.—There is not so much freedom in making three phase transformer connections, as with single or two phase, because the three phases are inseparably interlinked. However, the system gives rise to several methods of transformer connection, which are known as:

1. Star;
2. Delta;
3. Star-delta;
4. Delta-star.



FIGS. 1,992 to 1,995.—Three phase transformer connections. Fig. 1,992 delta connection; fig. 1,993 star connection; fig. 1,994 delta-star connection; fig. 1,995 star-delta connection.

Delta Connection.—In the delta connection both primaries and secondaries are connected in delta grouping, as in fig. 1,992.

Star Connection.—This method consists in connecting both the primaries and secondaries in star grouping, as in fig. 1,993.

Delta-star Connection.—In this method the primaries are connected in delta grouping and the secondaries in star grouping, as in fig. 1,994.

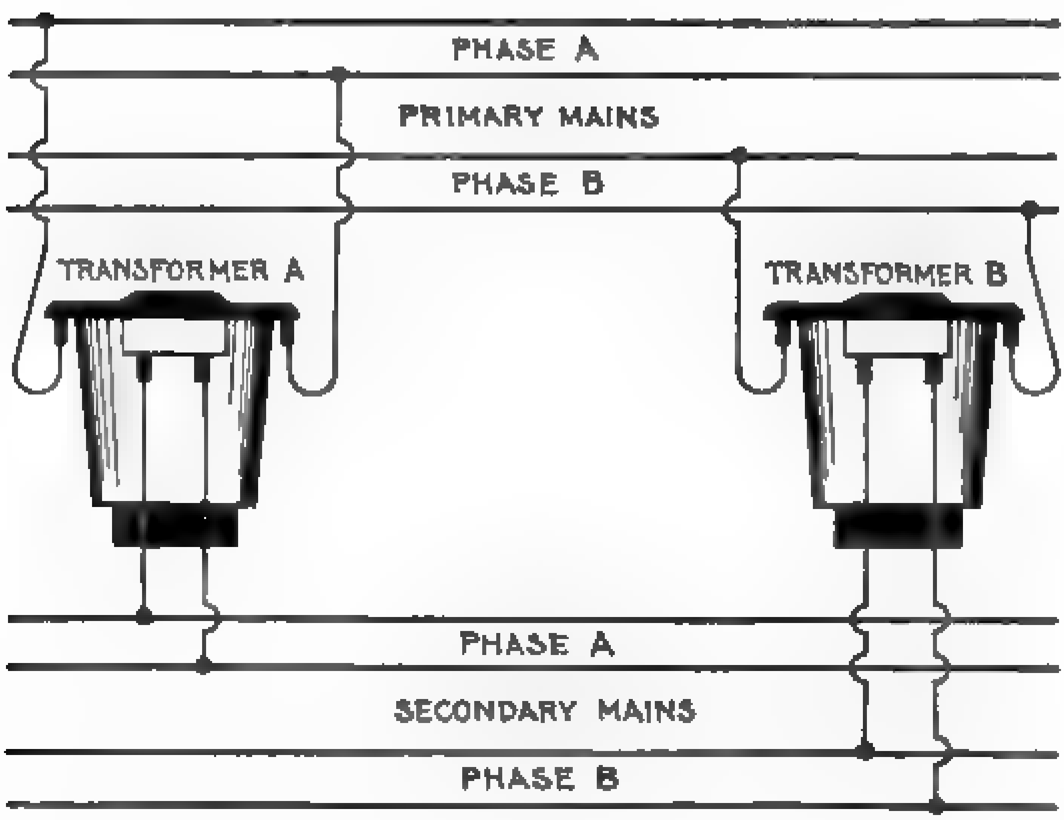


FIG. 1,996.—Two phase transformer connections. Two single phase transformers are used and connections made just as though each phase were an ordinary single phase system.

Star-delta Connection.—This consists in connecting the primaries in star grouping, and the secondaries in delta grouping, as in fig. 1,995.

Ques. What advantage has the star connection over the delta connection?

Ans. Each star transformer is wound for only 58% of the line voltage. In high voltage transmission, this admits of much smaller transformers being built for high pressure than possible with the delta connection.

Ques. What advantages are obtained with the delta connection?

Ans. When three transformers are delta connected, one may be removed without interrupting the performance of the circuit, the two remaining transformers in a manner acting in series to carry the load of the missing transformer.

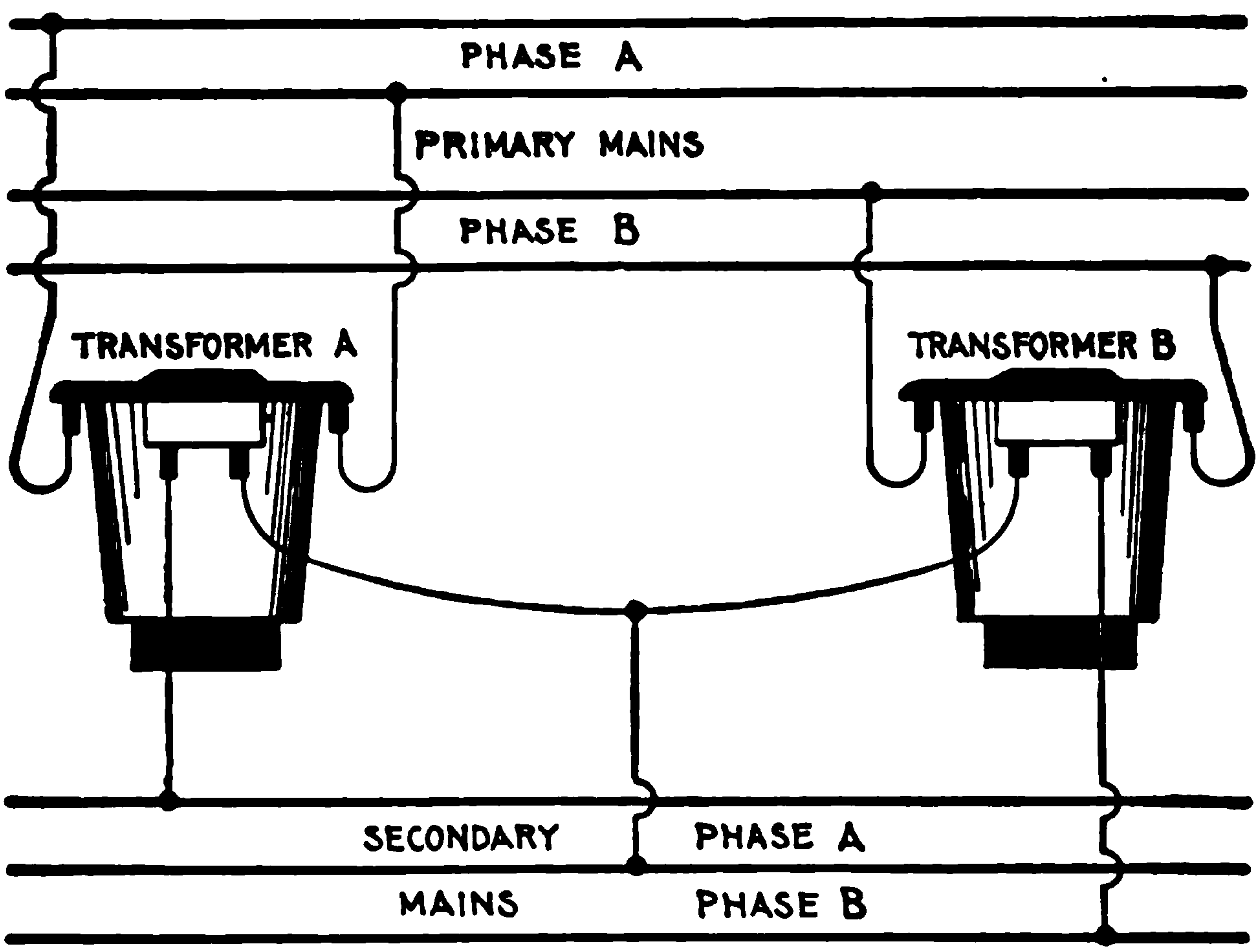


FIG. 1,997.—Two phase transformer connections, with secondaries arranged for three wire distribution, the primaries being independently connected to the two phases. In the three wire circuit, the middle or neutral wire is made about one-half larger than each of the two outer wires. In fig. 1,996 it makes no difference which secondary terminal of a transformer is connected to a given secondary wire, so long as no transformers are used in parallel. For example, referring to the diagram, the left hand secondary terminal of transformer, A, could just as well be connected to the lower wire of the secondary phase, A, and its right hand terminal connected to the upper wire, the only requirement being that the two pairs of mains shall not be "mixed"; that is, transformer, A, must not be connected with one secondary terminal to phase, A. and the other to phase, B. In the case shown by fig. 1,997, there is not quite so much freedom in making connections. One secondary terminal of each transformer must be connected to one of the outer wires and the other two terminals must be both connected to the larger middle wire of the secondary system. It makes no difference, however, which two secondary terminals are joined and connected to the middle wire so long as the other terminal of each transformer is connected to an outer wire of the secondary system.

The desire to guard against a shut down due to the disabling of one *transformer* has led to the extensive use of the delta connection, especially for the secondaries or low pressure side.

It should be noted that if one transformer be disabled, the efficiency of the other two will be greatly reduced. To operate a damaged three phase transformer, the damaged windings must be separated electrically from the other coils, the damaged primary and secondary being respectively short circuited upon themselves.

Ques. What kinds of transformers are used for three phase current?

Ans. Either a three phase transformer, or a separate single phase transformer for each phase.

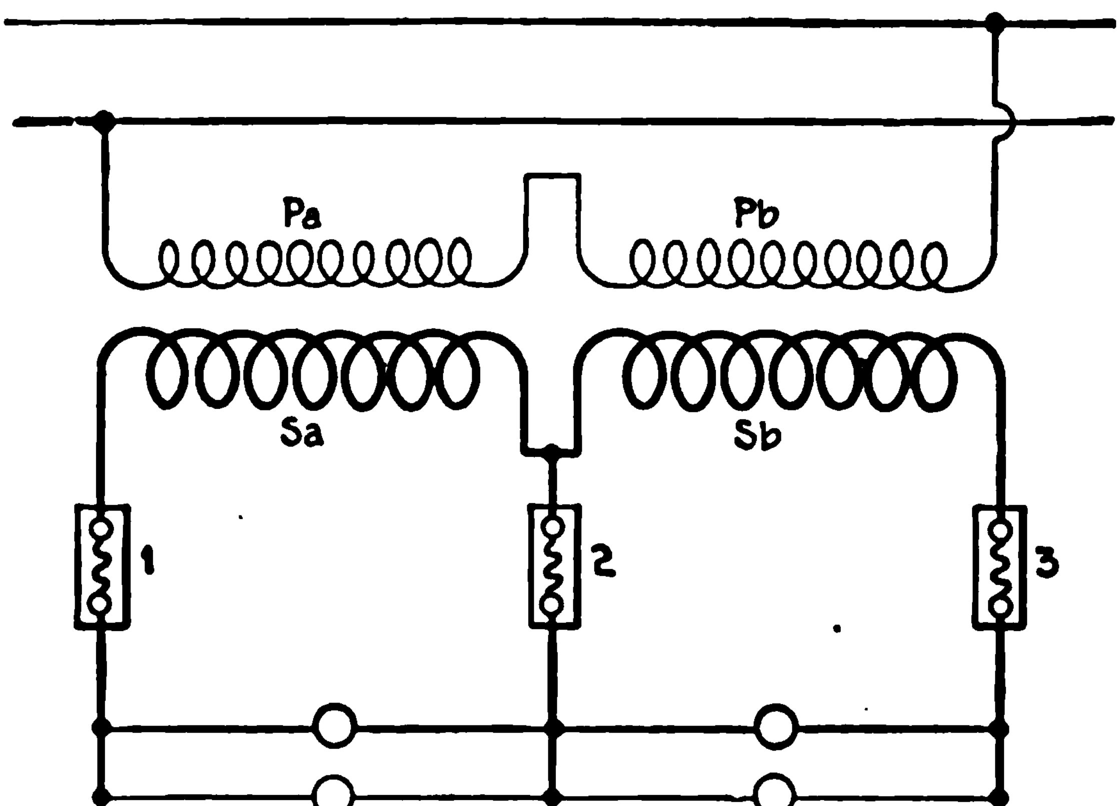
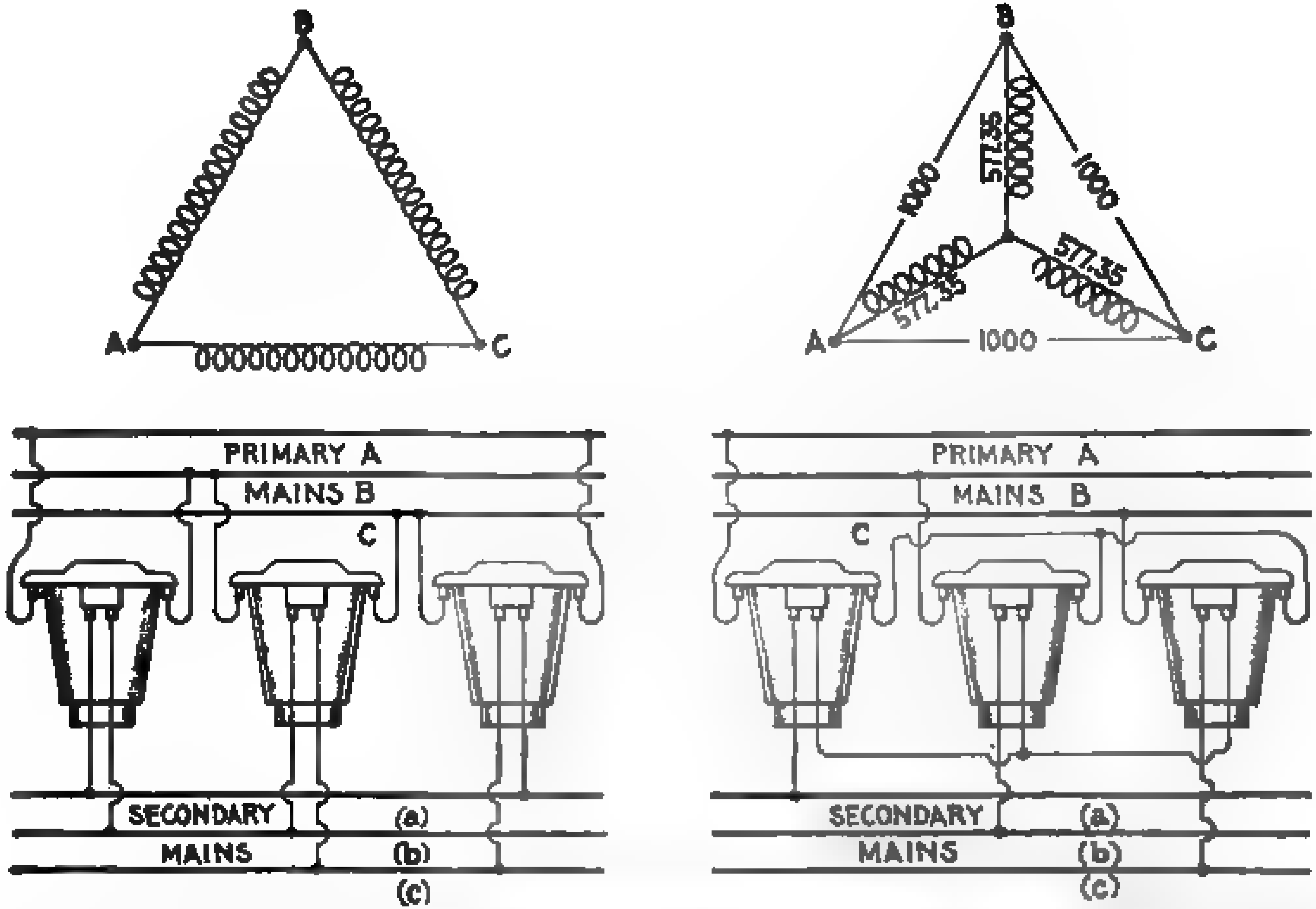


FIG. 1,998.—Three wire connections for transformer having two secondary sections on different legs of the core. If the secondary terminals be connected up to a three wire distribution, as here shown diagrammatically, it is advisable to make the fuse, 2, in the middle wire, considerably smaller than necessary to pass the normal load in either side of the circuit, because, should the fuse, 1, be blown, the secondary circuit through the section, Sa, will be open, and the corresponding half of the primary winding, Pa, will have a much higher impedance than the half of the primary winding, Pb, the inductance of which is so nearly neutralized by the load on the secondary winding, Sb. The result will be that the voltage of the primary section, Pa, will be very much greater than that of the section, Pb, and as the sections are in series the current must be the same through both halves of the winding; the drop or difference of pressure, therefore, between the terminals of Pa will be much higher than that between the terminals of Pb, consequently, the secondary voltage of Sb will be greatly lowered and the service impaired. As the primary winding, Pa, is designed to take only one-half of the total voltage, the unbalancing referred to will subject it to a considerably higher pressure than the normal value; consequently, the magnetic density in that leg of the transformer core will be much higher than normal, and the transformer will heat disastrously. If the fuse, 2, in the middle wire be made, say, one-half the capacity of each of the other fuses, this condition will be relieved by the blowing of this fuse, and as the lamps in the live circuit would not be anywhere near candle power if the circuit remained intact, the blowing of the middle fuse will not be any disadvantage to the user of the lamps. Some makers avoid the contingency just described by dividing each secondary coil into two sections and connecting a section on one leg in series with a section on the other leg of the core, so that current applied to either pair of the secondary terminals will circulate about both legs of the core.



FIGS. 1,999 to 2,002.—Three phase delta, and star connections using three transformers. There are two ways of connecting up the primaries and secondaries, one known as the "delta" connection, and illustrated diagrammatically by fig. 1,999, and the other known as the "star" connection, and illustrated by fig. 2,001. In both diagrams the line wires are lettered, A, B and C. Fig. 2,000 shows the primaries and secondaries connected up delta fashion, corresponding to fig. 1,999, and fig. 2,002 shows them connected up star fashion, corresponding to fig. 2,001. In both of the latter sketches the secondary

wires are marked to correspond with the respective primary wires. When the primaries are connected up delta fashion, the voltage between the terminals of each primary winding is the same as the voltage between the corresponding two wires of the primary circuit, and the same is true of the secondary transformer terminals and circuit wires. The current, however, flowing through the transformer winding is less than the current in the line wire, for the reason that the current from any one line wire divides between the windings of two transformers. For example in figs. 1,999 and 2,000, part of the current from the line wire, A, will flow from A to B through the left hand transformer, and part from A to C through the right hand transformer, if the current in the line wire, A, be 100 amperes, the current in each transformer winding will be 57.735 amperes. When transformers are connected up star fashion, as in figs. 2,001 and 2,002, the current in each transformer winding is the same as that in the line wire to which it is connected, but the voltage between the terminals of each transformer winding is 57.735 per cent. of the voltage from wire to wire on the circuit. For example, if the primary voltage from A to B is 1,000 volts, the voltage at the terminals of the left hand transformer (from A to J) will be only 577.35 volts, and the same is true of each of the other transformers if the system is balanced. These statements apply, of course, to both primary and secondary windings, from which it will become evident that if the three transformers of a three phase circuit be connected up star fashion at the primaries, and delta fashion at the secondaries, the secondary voltage will be lower than if both sides are connected up star fashion. For example, if the transformers be wound for a ratio of 10 to 1, and are connected up with both primaries and secondaries alike no matter whether it be delta fashion or star fashion, the secondary voltage will be one-tenth of the primary voltage, but if the primaries be connected up star fashion on a 1,000 volt circuit, and the secondaries be connected up delta fashion, the secondary voltage will be only 57.735 volts, instead of 100 volts. The explanation of the difference between the voltage per coil in a delta system and that in a star system is that in the former each winding is connected directly across from wire to wire; whereas in the star system, two windings are in series between each pair of line wires. The voltage of each winding is not reduced to one-half, however, because the pressures are out of phase with each other, being 120°, or one-third of a cycle, apart, consequently, instead of having 500 volts at the terminals of each coil in fig. 2,001 the voltage is 577.35. The same explanation applies to the current values in a delta system. The current phase between A and B, in fig. 1,999, is 120° removed from that in the winding between A and C; consequently, the sum of the two currents, in the wire, A is 1.732 times the current in each wire, or, to state it the opposite way, the current in each winding is 57.735% of the current in the wire, A. It will be well for the reader to remember that in all cases pressures differing in phase when connected in series, combine according to the well-known law of the parallelogram of forces; currents differing in phase, and connected in parallel, combine according to the same law.

Ques. What points are to be considered in choosing between three phase and single phase transformers for three phase current transformation?

Ans. No specific rule can be given regarding the selection of single phase or three phase transformers since both designs are equally reliable; local conditions will generally determine which type is preferable.

The following general remarks may, however, be helpful:

Single phase transformers are preferable where only one transformer group is installed and where the expense of a spare transformer would not be warranted. In such installations the burn out of one phase of a three phase unit would cause considerable inconvenience for the reason that the whole transformer would have to be disconnected from the circuit before repairs could be made.

If single phase transformers be used and connected in delta on both primary and secondary,

the damaged transformer can be cut out with a minimum amo
trouble and the other two transformers can be operated at norma
perature open delta at 58 per cent. of the normal capacity of the
of three transformers, until the third unit can be replaced.

With a three phase shell type transformer, if both the prima
secondary be delta connected, trouble in one phase will not preve
use of the other two phases in open delta. By short circuitin
primary and secondary of the defective phase, and cutting it

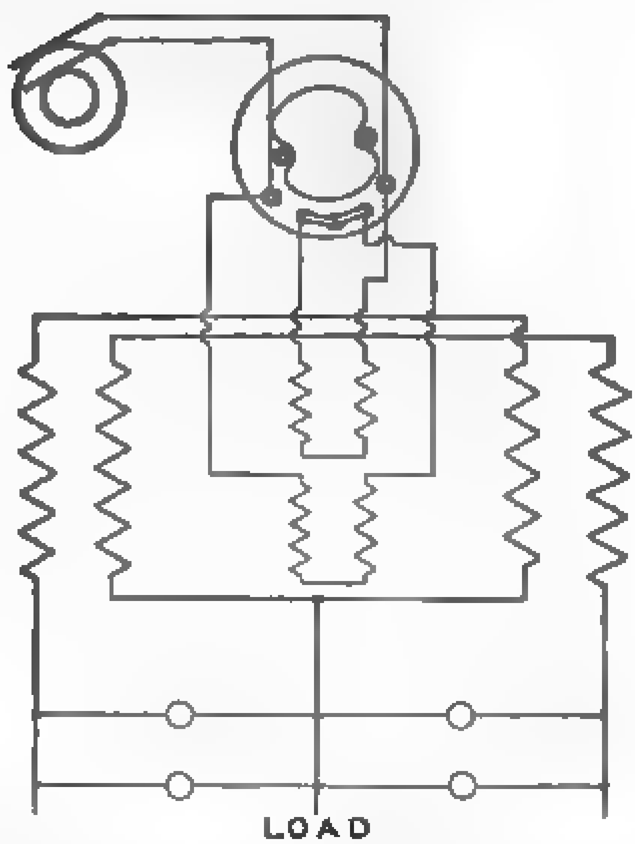


FIG. 2,008.—Diagram showing three wire secondary connections General Electric (t transformer. As will be seen, the method adopted consists of distributing equa each side of the primary coil, both halves of the secondary winding, so that each sec throughout its length is closely adjacent to the entire primary winding. In o insure the exact equality of resistance and reactance in the two secondary winding sary to obtain perfect regulation of the two halves, the inside portion of the sec winding on one side of the primary coil is connected in series with the outside por that on the other side. As a result, the drop of voltage in either side of the sec under any ordinary conditions of unbalanced load, does not exceed the listed reg drop. This particular arrangement is used because it is the simplest and best meth this construction.

circuit the magnetic flux in that section is entirely neutralized. cannot be done, however, with any but delta connected shell transformers.

Where a large number of three phase transformers can be used generally advisable to install three phase units, the following advar being in their favor as compared with single phase units:

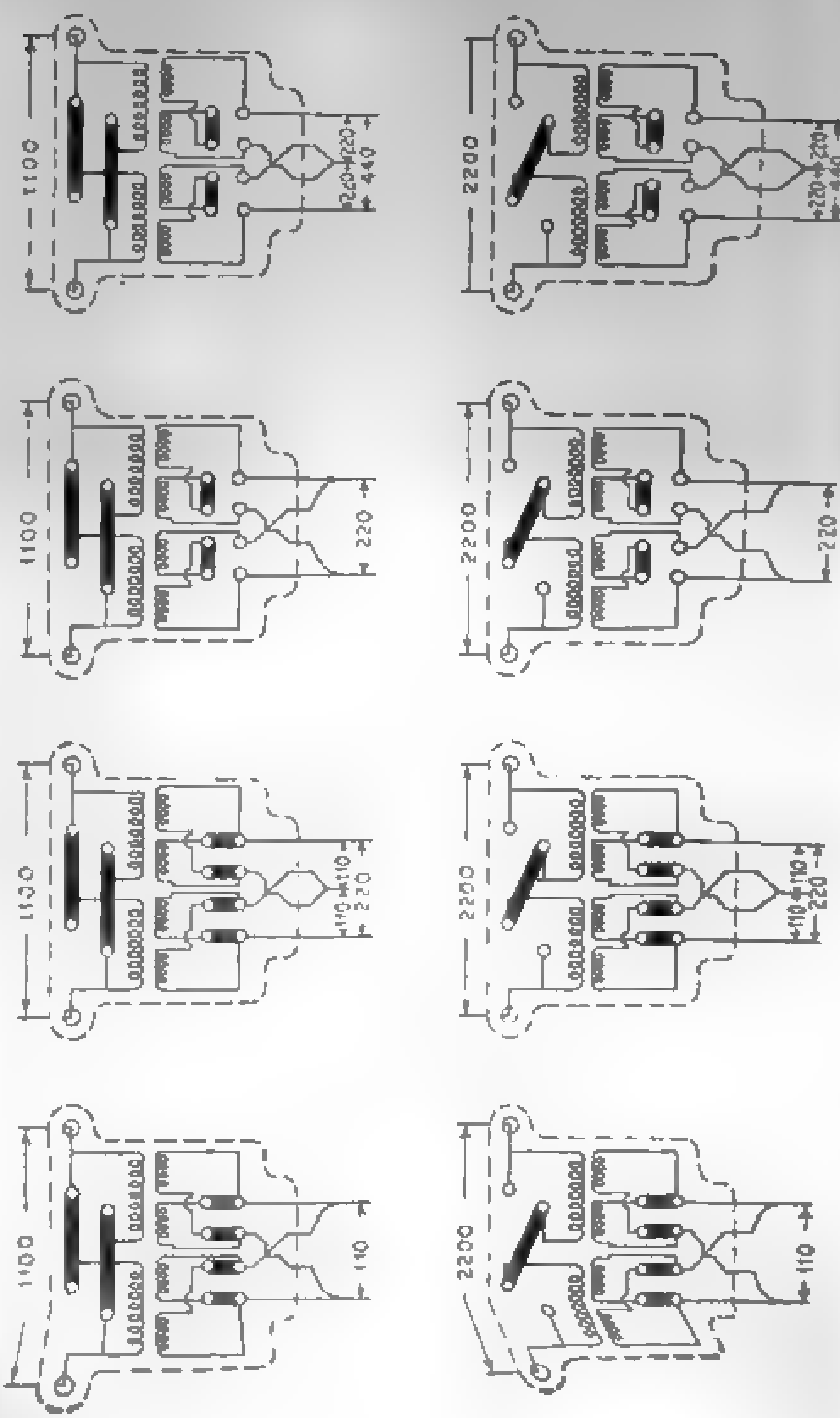
1. Require less floor space than three single phase units;
2. Weigh less than the single phase units;
3. Simpler connections, as only three primary and three secondary leads are generally brought out;
4. Transformer presents a symmetrical and compact appearance.

Ques. What is the character of the construction of three phase transformers?

Ans. The three phase transformer is practically similar to that of the single phase, except that somewhat heavier and larger parts are required for the core structure.

COMPARISON OF AIR BLAST, WATER COOLED, AND OIL COOLED TRANSFORMERS

Air blast type	Water cooled type	Oil cooled type
	1. COST	
A. First cost Necessarily more expensive than the water cooled type of similar rating.	Least expensive of all types.	Necessarily more expensive than the air blast and water cooled type of similar rating.
B. The installation is extremely simple. Moisture that may have collected on the surfaces during transportation or storage should be thoroughly dried out.	Being heavier than the air blast type, these transformers, as a rule, require heavier apparatus for installing. Both transformer and tank should be thoroughly dried out before being filled with oil. The oil is usually supplied in 50 gal. hermetically sealed steel barrels to minimize possibility of absorbing moisture during transportation.	Being heavier than the air blast and water cooled type, these transformers require heavier apparatus for installing. Both transformer and tank should be thoroughly dried out before being filled with oil.



,004 to 2,011.—Connections

C. Auxiliary apparatus A duct, or chamber, of considerable size is required under the transformers in order to conduct the cooling air to them. A blower outfit for supplying air is required.	In most cases, cooling water may be obtained with sufficient natural head. However, there are frequent cases in which it can be obtained only by the use of pumps. A system of piping for the cooling water and oil drainage is required, the cost of which depends, of course, on the station layout.	Do not require cooling water or blower.
D. Maintenance An occasional cleaning, for which a supply of compressed air at about 20 lb. pressure is recommended. The blower outfit requires no more care than any other similar apparatus.	A water pumping outfit would possibly require a trifle more attention than a blower outfit in which there are no valves or piping.	No air or water circulation to demand attention.

2. FLOOR SPACE

Always requires space for cooling apparatus.	Extra space only required when auxiliary pumping apparatus is necessary.	Only require space for the transformer as no extra apparatus is necessary.

3. LOCATION

As the transformers are open at the top they should not be located where there is much dust or dirt nor where water from any source is liable to fall on them. The blower should be so situated as to obtain clean dry air of a temperature not greater than 77° Fahr.	Transformers are completely enclosed but location should be such that no water will fall on leads or bushings. Location of auxiliary apparatus will depend on the station layout.	Transformers are completely enclosed but location should be such that no water will fall on leads or bushings. The building should be well ventilated. There is no auxiliary apparatus.

4. GENERAL APPEARANCE

Terminal leads may be located in the base and the air chamber may be used for conducting and distributing the connecting wiring. The absence of overhead wiring aids in simplifying the appearance of the station.	Leads are brought out of the top of the transformers. Water cooling pipes are connected at the top in most cases.	Leads are brought out of the top of the transformers.

5. OPERATION

Equal reliability in all three types.

While full load efficiencies are practically equal in the three designs, it is necessary to change the proportion of iron and copper losses somewhat as the copper loss of the air blast transformer is a smaller part of its total loss than of the water cooled and oil cooled types. As a result, the regulation of the air blast transformer is a trifle better.

6. GENERAL

The above information regarding selection of type is not applicable to air blast transformers for circuits materially in excess of 33,000 volts.

On account of the great thickness of the solid insulation needed and the consequent difficulty in radiating heat from the copper, it is impracticable to design the air blast type for more than this voltage. The oil immersed designs are therefore recommended for transformers above 33,000 volts.

Both oil cooled and water cooled types are available for all voltages, being restricted in this respect only by the limitations of transmission facilities.

Ques. How are transformers connected for four wire three phase distribution?

Ans. When the secondaries of three transformers are star

NOTE.—No special foundations are necessary for any type of transformer other than a good, even floor, having sufficient strength to support the weight.

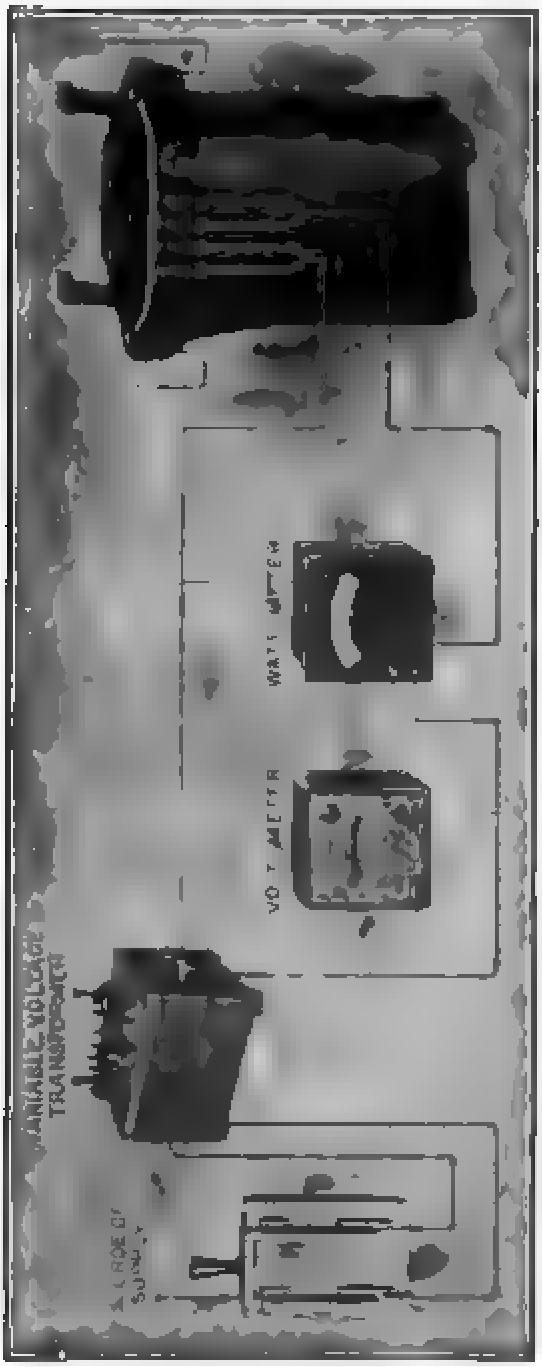


FIG. 2,012.—Method of determining core loss. Connect voltmeter and wattmeter as shown in the illustration to the low tension side of the transformer. By means of a variable voltage transformer bring the applied voltage to the point for which the transformer is designed. The wattmeter indicates directly the core loss, which includes a very small loss due to the current in the copper.

Cautions.—1. Make sure of the voltage and frequency. The manufacturers' tabulated statements refer to a definite voltage and frequency and these have a decided influence upon the core loss. 2. The high tension circuit must remain open during the test.

connected, a fourth wire may be run from the neutral point, thus obtaining the four wire system.

The voltage between any main wire and the neutral will be 57 per cent. of the voltage between any two main wires. For general distribution this system is desirable, requiring less copper and greater flexibility than other systems.

Three phase 200 volt motors may be supplied from the main wires and 115 volt lamps connected between each of the three main wires and the neutral; if the lamp load be very nearly balanced the current flowing in the neutral wire will be very small, as in the case of the ordinary three wire direct current system.

How to Test Transformers.—The troubles incident to gas or water service have their parallels in electric power distribution.

Companies engaged

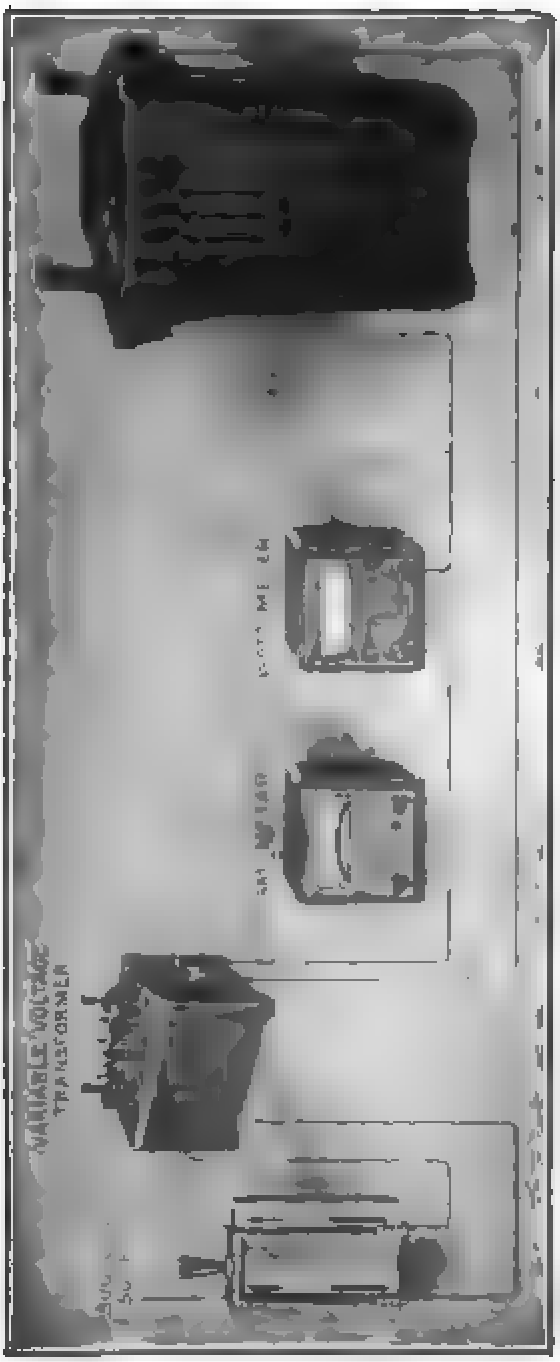


FIG. 2,013.—Method of determining copper loss. Connect ammeter and wattmeter to high tension side of transformer short circuit secondary leads, as shown in illustration, and by means of a variable voltage, adjust current to the full load value for which the transformer is intended. The wattmeter reading shows the copper loss at full load. The full load primary current of any transformer is found from the following equation

full load current = full load watts ÷ primary volts

EXAMPLE: To find proper full load current on a five kw. 2,200 volt transformer, divide 5,000 watts by 2,200 volts, the full load current will then be 2.27 amperes. A slight variation in primary current greatly increases or decreases the copper loss.

Remarks.—Copper loss increases with temperature because the resistance of the metal rises. Do not overload the current coil of the wattmeter. For greater accuracy the I^2R drop of potential method should be used.

in the former, cred a large percenta of their losses leaky valves a defective main The remedy m involve heavy e pense and the lo is often tolerate as the lesser two evils.

In electric pow er distribution th transformer tak in part the place the valve and pi system. **An i** ferior or **defecti** transformer **us** ally treats **bot** the central statio and its custome badly, being in th respect more im partial than the ga or water pipe whic may annoy but on of the intereste parties at a time.

Like a neglect or defective gas fi ture a transform can menace life, fai ing, however, to giv

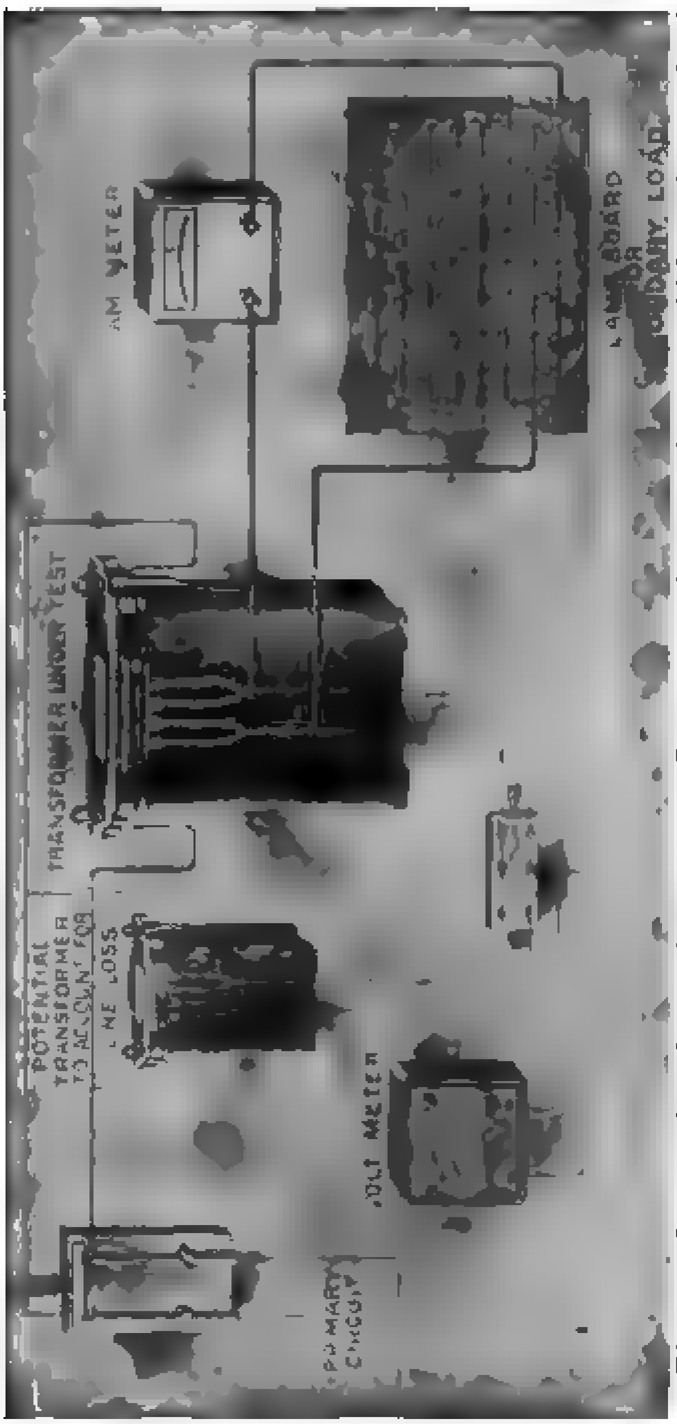


FIG. 2,014.—Diagram of connections for regulation test. Connect transformer under test to high tension supply circuit. A second transformer with same or other known change ratio is also to be connected up, as illustrated. By means of a double pole double throw switch, the voltmeter can be made to read the pressure on the secondary of either transformer. Supposing the same change ratio it is evident that if both remain unloaded the voltmeter will indicate the same pressure. A gradually increasing lamp load up to the limit of the transformer capacity, will be attended by a drop in pressure at the terminals. This drop can be read as the difference of the voltmeter indications, and when expressed in per cent. of secondary voltage stands for "regulation." **Remarks:** The auxiliary transformer is necessary in order to make sure of the high tension line voltage. A large transformer under test may cause primary drop in taking power. This must be set down against it in testing regulation. The second transformer gives notice of such drop, whatever be the cause. Figs. 2,012 to 2,014 used by courtesy of the Moloney Electric Co.

the warning the former gives, and with a more hidden threat on account of its location.

Apart from this, corresponding to an exasperated customer who complains at home and to his friends of dim lamps, blackened lamps, you will find in the power station the manager, who, also worried and in no better humor, contemplates the difference in meter readings at the end of the line.

His business does not increase and would not increase even if he could lower the rates, which he cannot do because of these meter readings.

He may be confident of his engines and generators, and that his line is up and all right, but he very seldom knows what the transformers are doing on top of

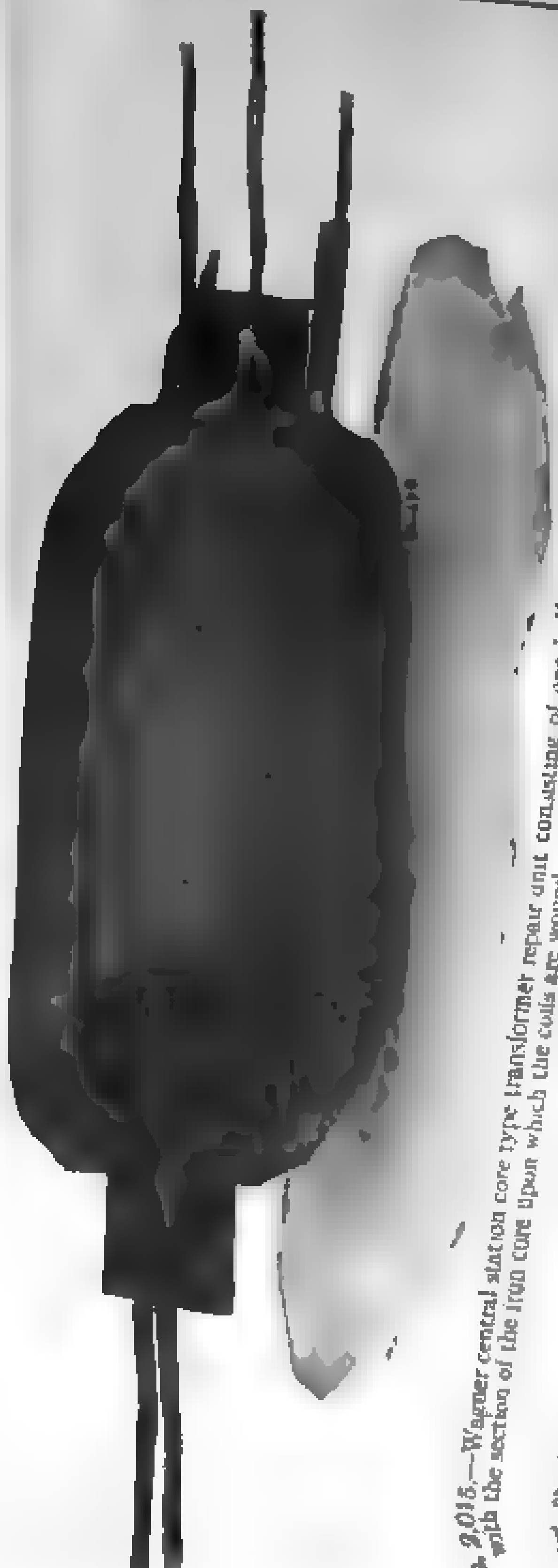


FIG. 2,015.—Wagner central station core type transformer repair unit consisting of one half set of primary and secondary winding together with the section of the iron core upon which the coils are wound.

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An ammeter, voltmeter and wattmeter are required to make the tests. Losses are small in **good** transformers and hence the instruments **should be accurate.** For the same reason instruments should be chosen of the proper capacity to give their best readings. If there be any doubt about the testing instruments being correct, they should be calibrated before being

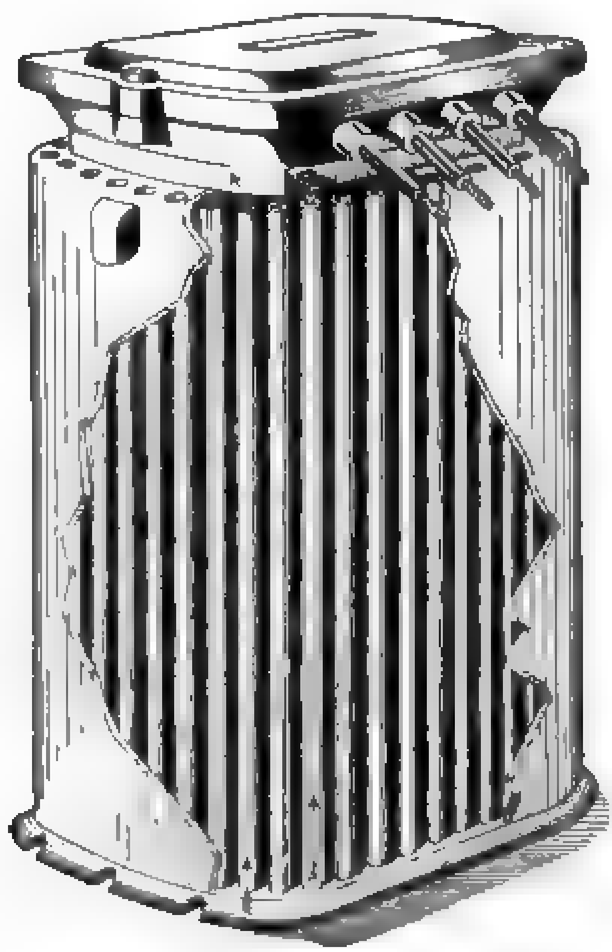


FIG. 2,016.—Moloney tubular air draft oil filled transformer. The case is made of cast iron, with large steel tubes passing from the bottom through the top. In operation the air in the tubes becomes hot and expands; a draft is thus produced which carries away considerable heat.

used. The testing circuits should be properly fused for the protection of the instruments. It is hardly logical, but a very common practice is to mistrust meters and to watch them closely, while the transformers are guilty of theft unchallenged, and keep busily at it on a large scale.

Transformer Operation with Grounded Secondary.—The operation of a transformer with a grounded secondary has been approved by the American Institute of Electrical Engineers, and by the National Board of Fire Underwriters.

This method of operation effectually prevents a high voltage occurring upon the low tension wires in case of a breakdown or other electrical connections occurring between the primary and secondary windings.

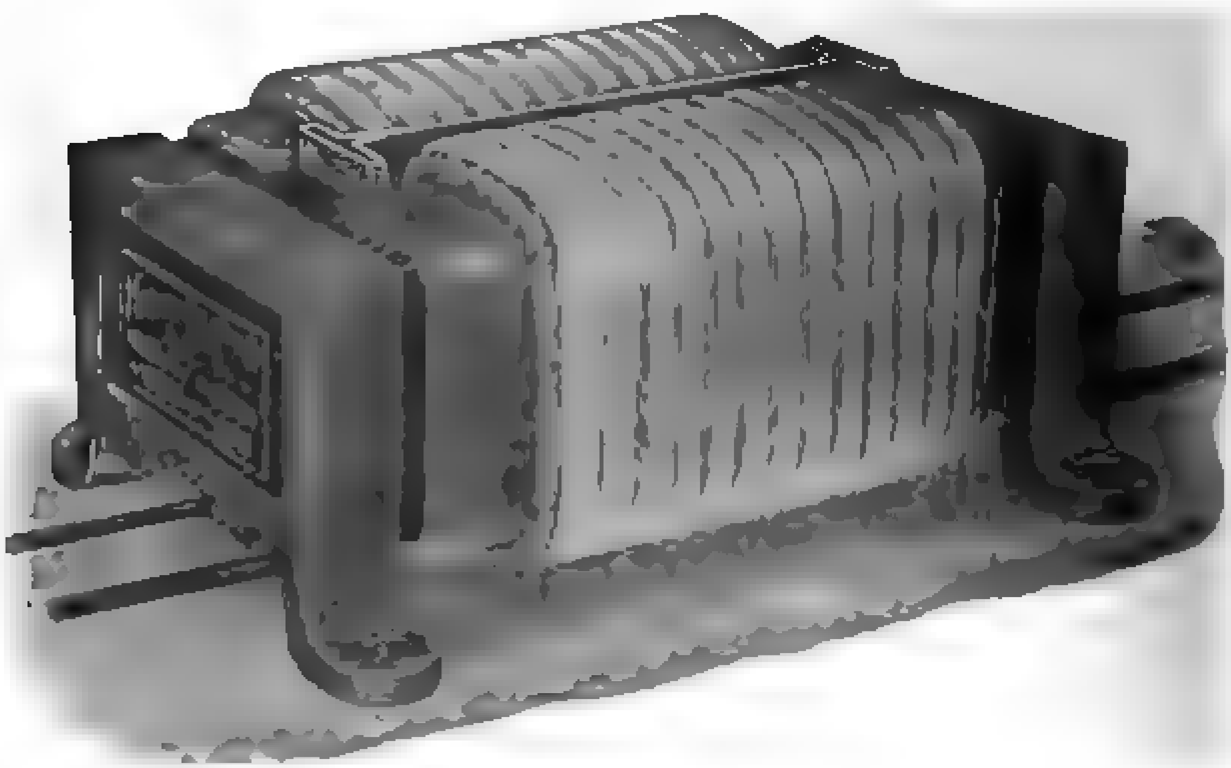


FIG. 2,017.—Moloney pressure transformer adapted for switchboard work in connection with voltmeters, wattmeters, etc., in sizes from 25 to 500 watts.

In case of a breakdown without the secondary grounded, any one touching a part of the low tension system, such as a lamp socket, might receive the full high pressure voltage. With the low tension grounded, the fuse in the high tension circuit *will blow* and the fault be discovered upon replacing it.

Transformer Capacity for Motors.—The voltage regulation of a well designed transformer is within 3 per cent. of its rated voltage on a non-inductive load such as incandescent lamps, but when motors are connected to the circuit their self-induction causes a loss of 5 per cent. or more, and if the load be fluctuating, it is better to use independent transformers for the motor, which will prevent considerable fluctuations in the incandescent lamps. Arc lamps do not show slight voltage changes as much as incandescent lamps. The proper rating of transformers for two phase and three phase induction motors is given in table on the next page.

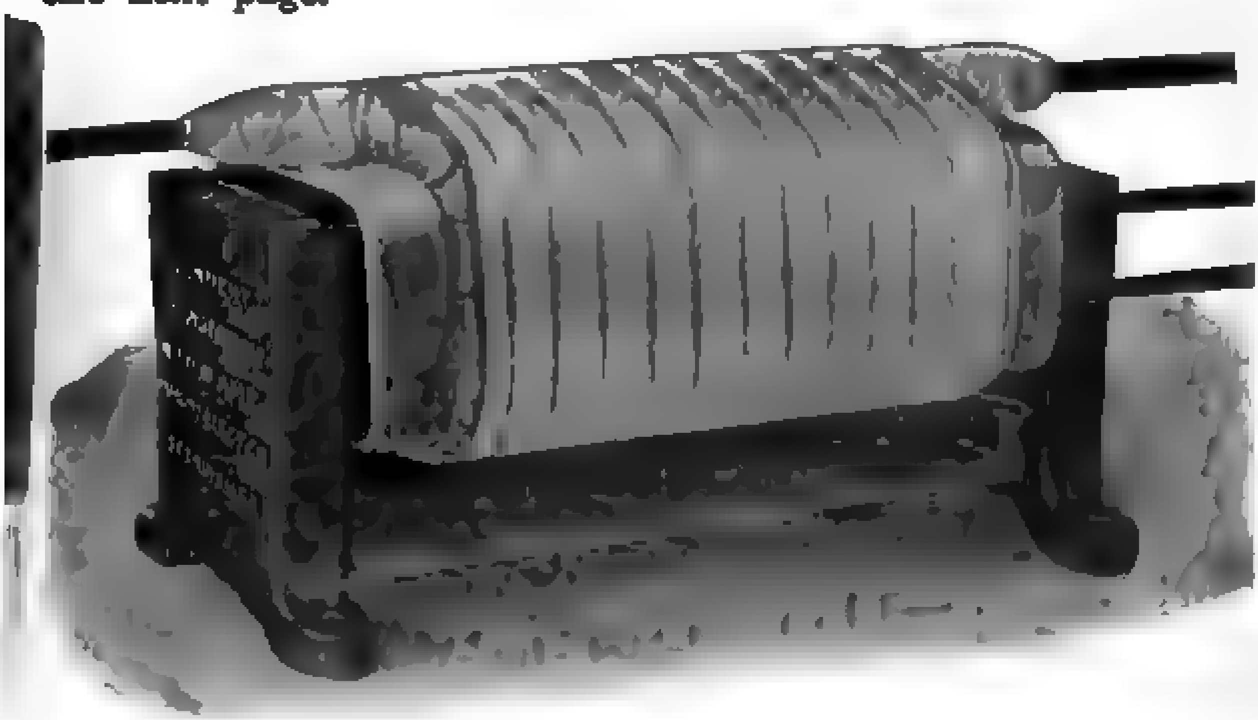


FIG. 2,018.—Moloney current transformer switchboard or indoor type. It is used ordinarily for insulating an ammeter, a current relay, the current coil of a watt meter or watt hour meter from a high tension circuit, for reducing the line current to a value suitable for these instruments.

A three phase induction motor may be operated from three single phase transformers or one three phase transformer. While the one three phase transformer greatly reduces the space and simplifies the wiring, the use of three single phase transformers

is more flexible and, in case one transformer burns out, the connection can be readily changed so that two transformers will operate the motor at reduced load until the burned out transformer is replaced or repaired.

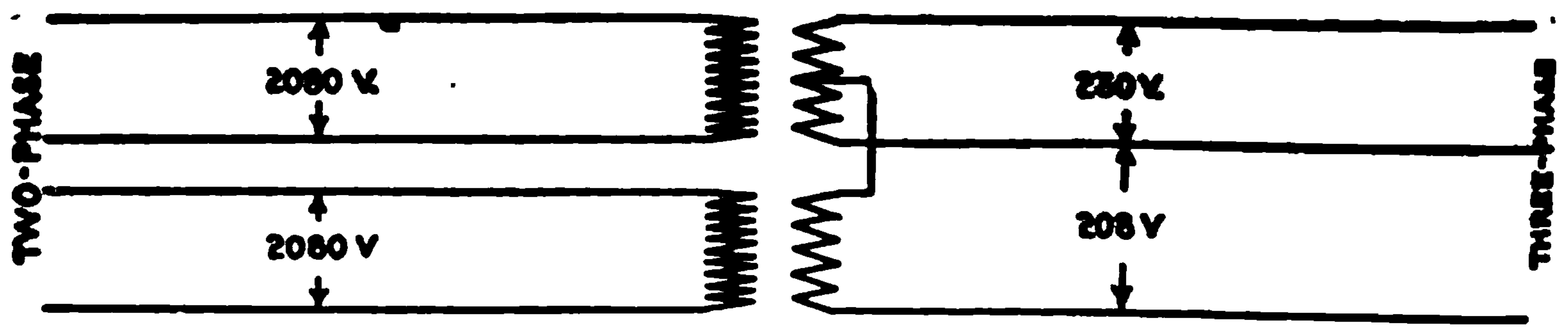


FIG. 2,019.—Diagram showing a method of operating a three phase motor on a two phase circuit, using a transformer having a tap made in the middle of the secondary winding, so as to get the necessary additional phase. While this does not give a true balanced three phase secondary, it is close enough for motor work. In the above arrangement, the main transformer supplies 54 per cent. of the current and the other with the split winding 46 per cent.

It is well to allow one kilowatt per horse power of the motor in selecting the size for the transformers, excepting in the small sizes when a little larger kilowatt rating is found to be the most desirable.

Transformers for Two and Three Phase Motors

Delivered voltage of circuit	Single phase transformer voltages			
	110 volt motor		220 volt motor	
	Primary	Secondary	Primary	Secondary
1,100	1,100	122	1,100	244
2,200	2,200	122	2,200	244

Very small transformers should not be used, even when the motor is large compared to the work it has to do, as the heavy starting current may burn them out.

The following tables give the proper sizes of transformer for three types of induction motor and the approximate current *taken by three* phase induction motors at 220 volts.

Capacities of Transformers for Induction Motors

Size of motor horse power	Kilowatts per transformer		
	Two single phase transformers	Three single phase transformers	One three phase transformer
1	0.6	0.6	
2	1.5	1.0	2.0
3	2.0	1.5	3.0
5	3.0	2.0	5.0
7	4.0	3.0	7.5
10	5.0	4.0	10.0
15	7.5	5.0	15.0
20	10.0	7.5	20.0
30	15.0	10.0	30.0
50	25.0	15.0	50.0
75	40.0	25.0	75.0
100	50.0	30.0	100.0

Current taken by Three Phase Induction Motors at 220 Volts

Horse power of motor	Approximate full load current	Horse power of motor	Approximate full load current
1	3.2	20	50.
2	6.0	30	75.
3	9.0	50	125.
5	14.0	75	185.
10	27.0	100	250.
15	40.0	150	370.

Transformer Connections for Motors.—Fig. 2,020 shows the connection of a three phase so called delta connected transformer with the three primaries connected to the lines leading from the alternator and the three secondaries leading to the motor.

The connections for a three phase motor using two transformers is shown in fig. 2,021 and is identical with the previous

arrangement, except that one transformer is left out and the other two made correspondingly larger.

The copper required in any three wire three phase circuit for a given power and loss is 75 per cent. that necessary with the two wire single phase or four wire two phase system having the same voltage between lines.

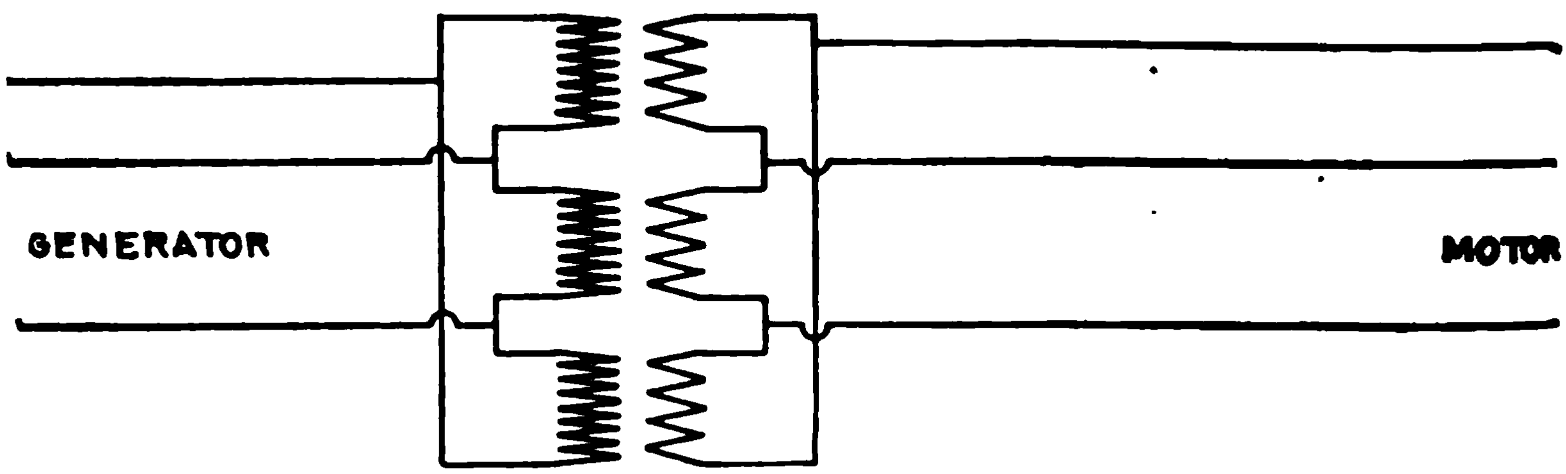


FIG. 2,020.—Three phase motor transformer connections; the so-called **Delta connected** transformers.

The connections of three transformers for a low tension system of distribution by the four wire three phase system are shown in fig. 2,022. The three transformers have their primaries joined in delta connection and the secondaries in "Y" connection. The three upper lines of the secondary are the three main three phase lines, and the lowest line is the common neutral.

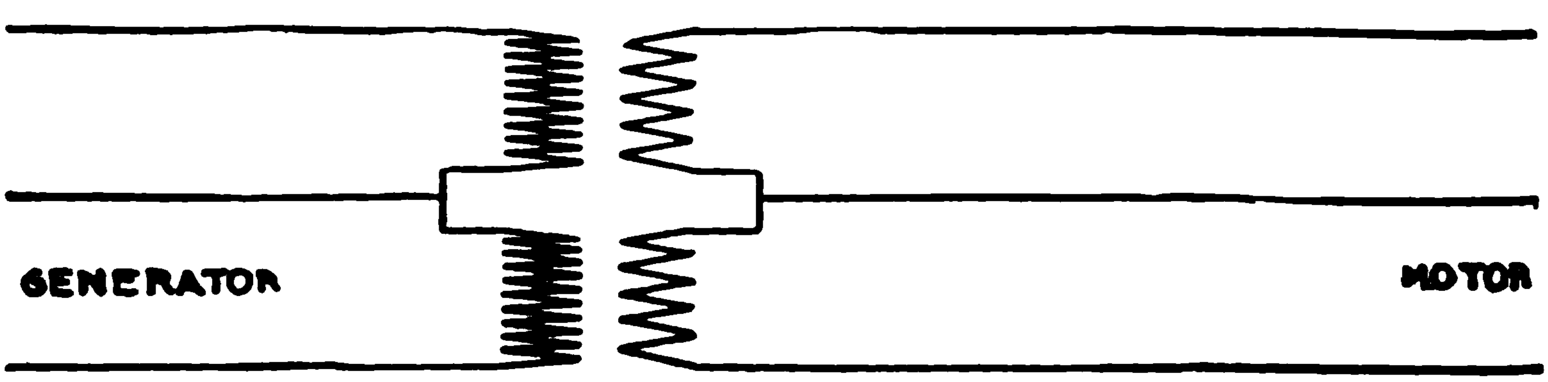


FIG. 2,021.—Three phase motor connections using two transformers.

The voltage across the main conductors is 200 volts, while that between either of them and the neutral is 115 volts; 200 volt motors should be joined to the mains while 115 volt lamps are connected between the mains and neutral. The arrangement is similar to the

Edison three wire system and the neutral carries current only when the lamp load is unbalanced.

The voltage between the mains should be used in calculating the size of wires, and the size of the neutral wire should be made in proportion to each of the main conductors that the lighting load is to the total load.

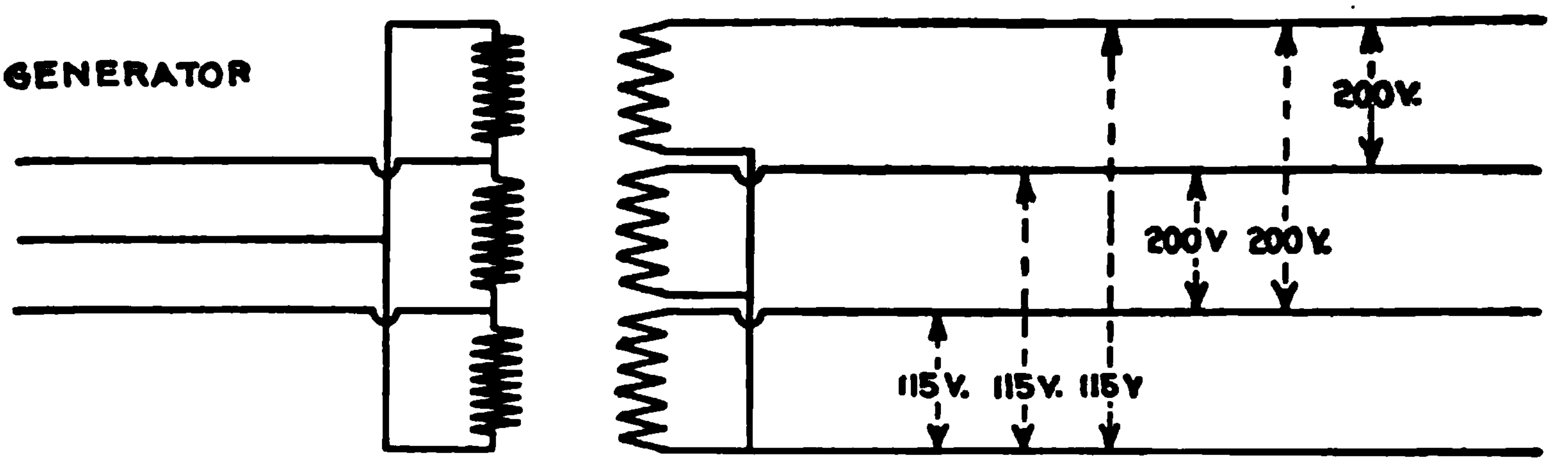


FIG. 2,022.—Delta-star connection of three transformers for low pressure, three phase, four wire system.

When lights only are used the neutral should be the same as the main conductors. The copper required in such a system for a given power and loss is about 33.3 per cent. as compared with a two wire single phase system or a four wire two phase system using the same voltage.

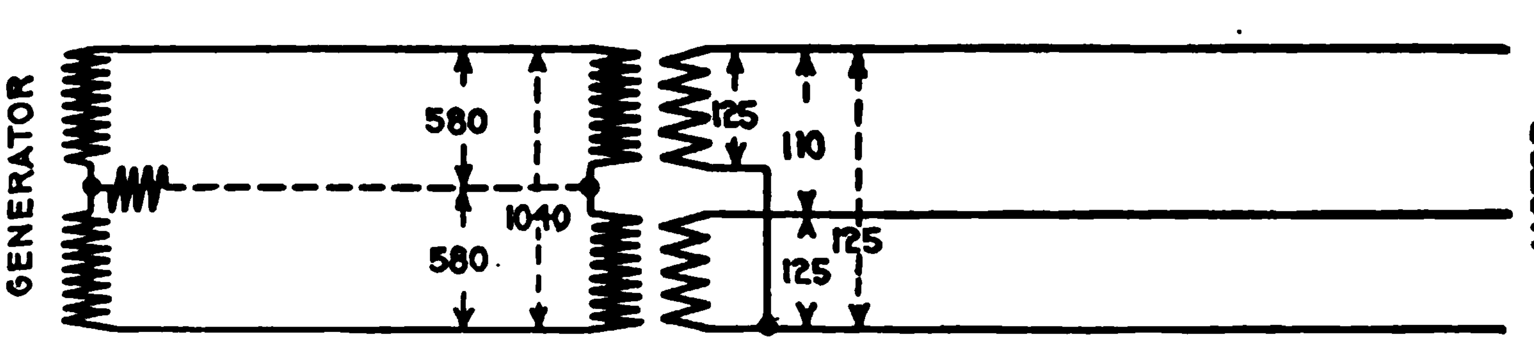


FIG. 2,023.—Diagram of transformer connections for motors on the monocyclic system.

Monocyclic Motor System.—Motors on the monocyclic system are operated from two transformers connected as shown in fig. 2,023. In the monocyclic system the single phase current is used to supply the lighting load and two wires only are necessary, but if a self-starting induction motor be required, a third or *teaser wire* is brought to the motor and two transformers used.

The teaser wire supplies the quarter phase current required to start the motor, which afterwards runs as a single phase synchronous motor and little or no current flows through the teaser circuit as long as the motor keeps in synchronism; in case it fall behind, the teaser current tends to bring it up to speed instead of the motor stopping, as would be the case of a single phase motor.

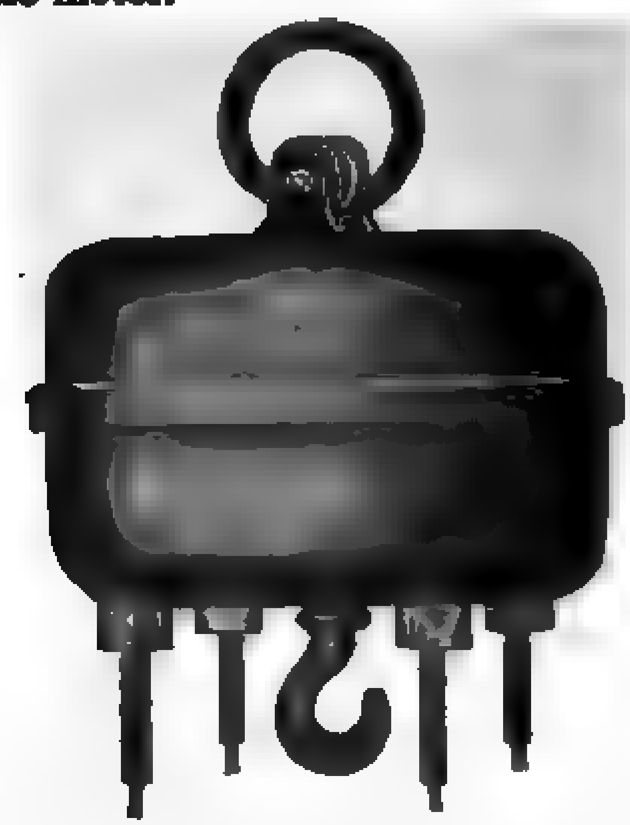
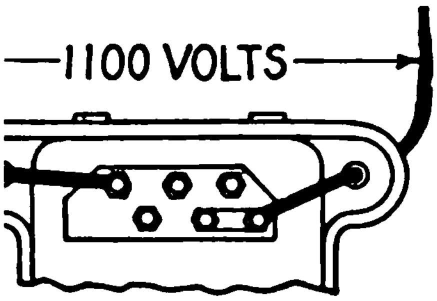
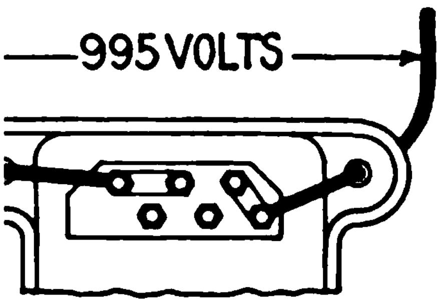
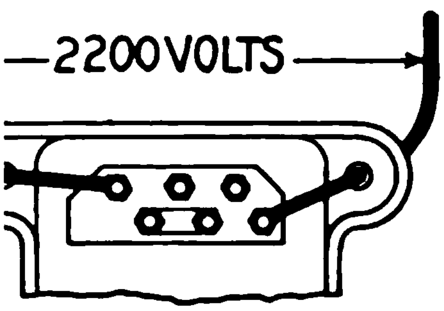
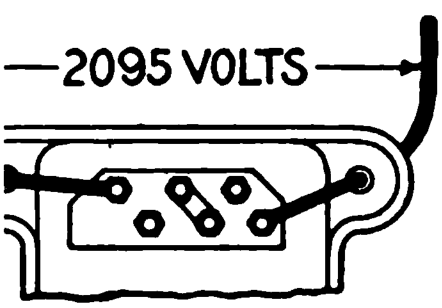
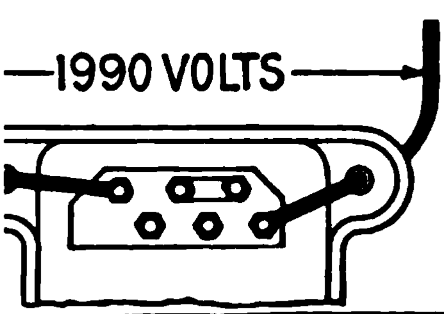


FIG. 2,024.—Moloney flaming auto type arc lamp transformer for 110 volts primary to 55 volts secondary. A hook in bottom of case provides means for suspension of lamp. The transformer may be operated on circuits from 100 to 120 volts primary, 50 to 60 volts secondary. The secondary capacity is 8 to 12 amperes.

The voltage of the transformers should be tested by means of a voltmeter or two incandescent lamps joined in series, before starting up the motor, to see if the proper transformer connections have been made and prevent an excessive flow of current.

If one of the transformers be reversed the voltage will be almost doubled; in fact, it is a good plan to check up all the transformer connections w[illegible] which will often save a burn out.

angement of links on e connecting board	Primary coils will be connected in	For circuit voltage normal at	Ratio of transformation at no load: with secondary coils in multiple	Ratio of transformation at no load: with secondary coils in series.
	Multiple	1,100	10:1	5:1
	Multiple	1,100	9.05:1	4.52:1
	Series	2,200	20:1	10:1
	Series	2,200	19.05:1	9.5:1
	Series	2,200	18.1:1	9.05:1

2,025 to 2,029.—Diagrams of Wagner transformer connection board, and table showing arious arrangements of the terminal links, corresponding transformation ratios, and itable primary voltages.

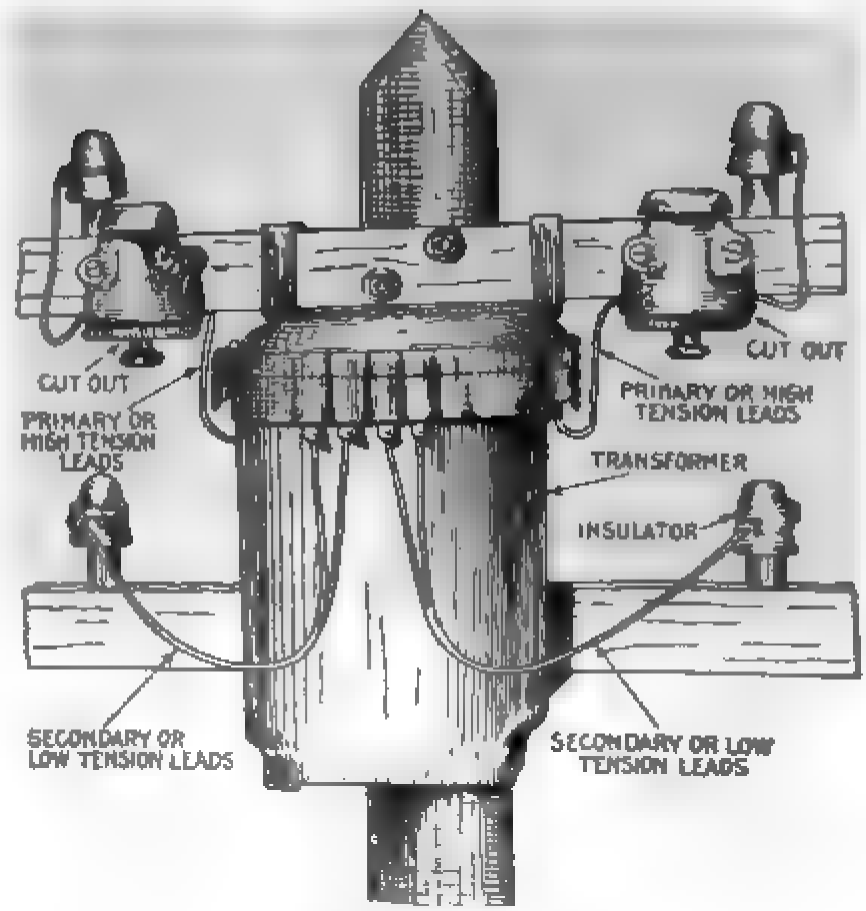


FIG. 2,030.—Installation of a transformer on pole; view showing method of attacl disposition of the primary and secondary leads, cutouts, etc.

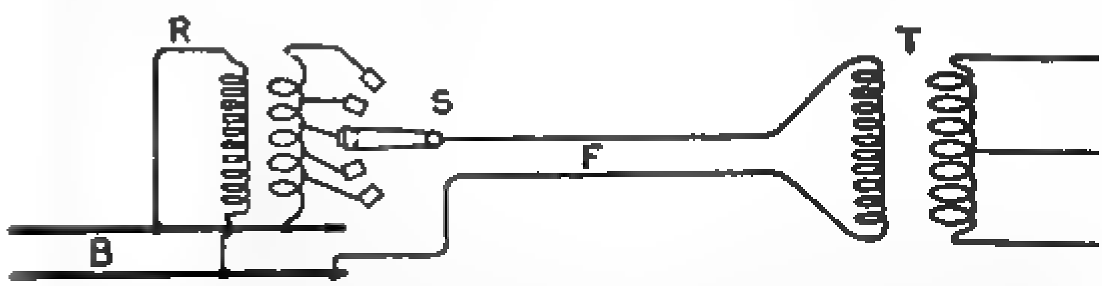


FIG. 2,031 —Diagram of static booster or regulating transformer. It is used for the pressure on feeders. In the figure, B are the station bus bars, R the regul former, F the two wire feeders, and T a distant transformer feeding into the lo three wire distributing network N. The two ends of the primary, and one secondary of R, are connected to the bus bars as shown The other end of the as well as a number of intermediate points, are joined up to a multiple way to which one of the feeder conductors is attached, the other feeder main being to the opposite bus bar. As will be evident from the figure, by manipulatu volts may be added to the bus bar pressure at will, and the drop along F compe R is a step transformer the total secondary difference of pressure being com small. The above device possesses rather serious drawbacks, in that the swi to carry the main current, and that the supply would be stopped if the switch order. Kapp improved on the arrangement by putting the switch in the prima

CHAPTER LIII

CONVERTERS

The alternating current must change to a direct current in many cases as in railroad work because the induction motor is not so satisfactory as the direct current series motor and the alternating current series motor is slow in coming into general use.

In all kinds of electrolytic work, transformation must be made, and in many cities where the direct current system was started, it is still continued for local distribution, but the large main stations generating alternating currents and frequently located some distance away from the center of distribution have replaced a number of small central stations.

Transformation may be made by any of the following methods:

1. Rotary converters;
2. Motor generator sets;
3. *Mercury vapor rectifiers;
4. *Electrolytic rectifiers.

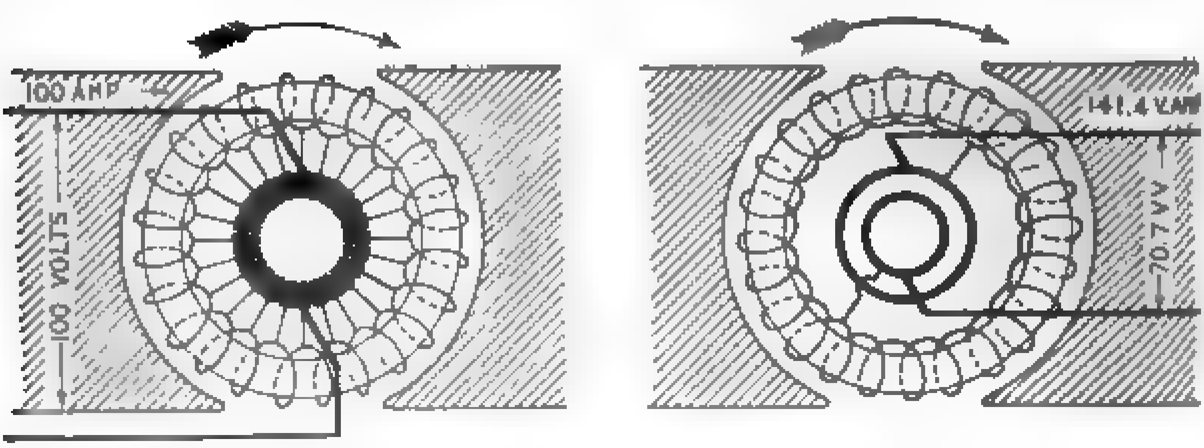
Strictly speaking, *a converter is a revolving apparatus for converting alternating current into direct current or vice versa;* it is usually called a rotary converter and is to be distinguished from the other methods mentioned above.

Broadly, however, a converter may be considered as *any species of apparatus for changing electrical energy from one form into another.*

*NOTE.—Rectifiers are explained in detail in Chapter LIV.

According to the standardization rules of the A. I. E. E. converters may be classified as:

1. **Direct current converters;**
2. **Synchronous converters;**
3. **Motor converters;**
4. **Frequency converters;**
5. **Rotary phase converters.**



FIGS. 2,032 and 2,033. Gramme ring dynamo and alternator armatures illustrating **converter** operation. The current generated by the dynamo is assumed to be 100 amperes. Now, suppose, an armature similar to fig. 2,032 to be revolving in a similar field, but let its windings be connected at two diametrically opposite points to two slip rings on the axis, as in fig. 2,032. If driven by power, it will generate an alternating current. As the maximum voltage between the points that are connected to the slip rings will be 100 volts, and the virtual volts (as measured by a voltmeter) between the rings will be 70.7 ($= 100 \div \sqrt{2}$), if the power applied in turning this armature is to be 10 kilowatts, and if the circuit be non-inductive, the output in virtual amperes will be $10,000 \div 70.7 = 141.4$. If the resistances of each of the armatures be negligibly small, and if there be no frictional or other losses, the power given out by the armature which serves as motor will just suffice to drive the armature which serves as generator. If both armatures be mounted on the same shaft and placed in equal fields, the combination is a **motor dynamo**. In actual machines the various losses are met by an increase of current to the motor. Since the armatures are identical, and as the similarly placed windings are passed through identical magnetic fields, one winding with proper connections to the slip rings and commutator will do for both. In this case only one field is needed; such a machine is called a **converter**.

A direct current converter converts from a direct current to a direct current.

A synchronous converter (commonly called a *rotary converter*) converts from an alternating current to a direct current.

A motor converter is a combination of an induction motor with a synchronous converter, the secondary of the former feeding the armature of the latter with current at some frequency other than the impressed frequency; that is, it is a synchronous converter in combination with an induction motor.

[redacted]

A Frequency Converter (preferably called a *frequency changer*) converts alternating current at one frequency into alternating current of another frequency, with or without a change in the number of phases or voltages.

A Rotary Phase Converter changes alternating current of one or more phases into alternating current of a different number of phases, but of the same frequency.

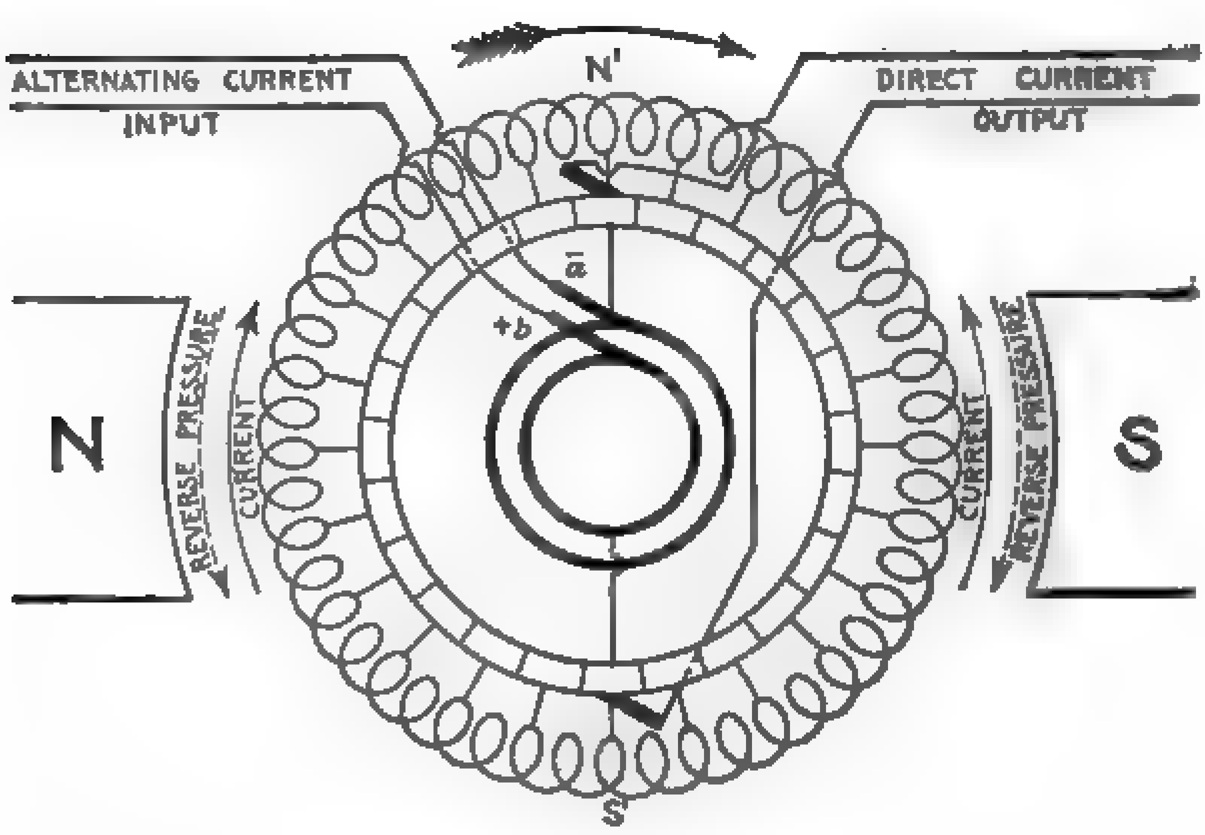


FIG. 2,034.—Diagram of ring wound single phase rotary converter. It is a combination of a synchronous motor and a dynamo. The winding is connected to the commutators in the usual way, and divided into two halves by leads connecting segments 180° apart to collector rings. A bipolar field is shown for simplicity; in practice the field is multipolar and energised by direct current.

Rotary Converters.—The synchronous or rotary converter consists of a synchronous motor and a direct current generator combined in one machine. It resembles a direct current generator with an unusually large commutator and an auxiliary *set of collector rings.*

[redacted]

Ques. In general, how does a rotary converter operate?

Ans. On the collector ring side it operates as a synchronous motor, while on the commutator side, as a dynamo.

Its design in certain respects is a compromise between alternating current and direct current practice most noticeably with respect to the number of poles and speed.

Ques. Upon what does the speed depend?

Ans. Since the input side consists of a synchronous motor,

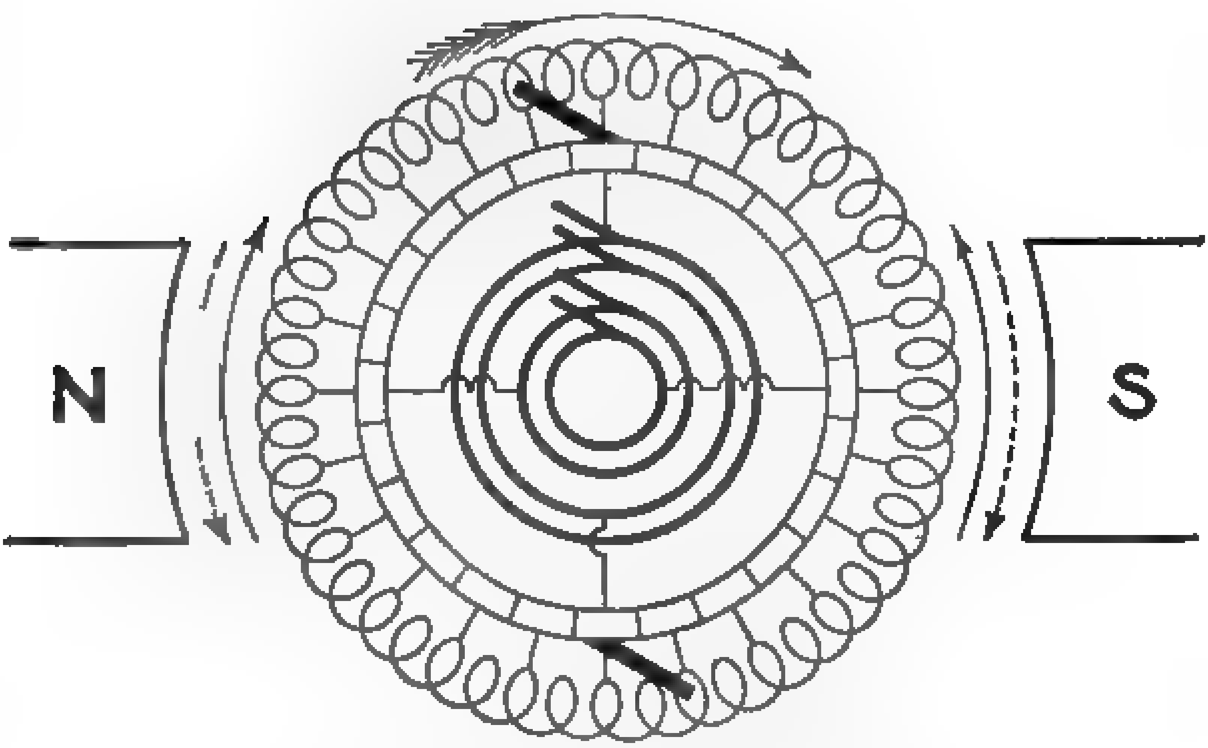


FIG. 2,035.—Diagram of two phase rotary converter. This is identical with the single phase machine with the exception that another pair of collector rings are added, and connected to points on the winding at right angles to the first, giving four brushes on the alternating side for the two phase current. The pressure will be the same for each phase as in the single phase rotary. Neglecting losses the current for each phase will be equal to the direct current $\times 1 + \sqrt{2}$=direct current $\times$ .707.

the speed is governed by the frequency of the alternating current supplied, and the number of poles.

Fig. 2,034 is a diagram of a ring wound rotary converter. This style winding is shown to simplify the explanation. In practice drum wound armatures are used, the operation, however, is the same.

With this simple machine the following principles can be demonstrated:

1. If the coil be rotated, alternating currents can be taken from the collector rings and it is called an alternator.

2. By connecting up the wires from the commutator segments, a direct current will flow in the external circuit making a dynamo.

3. Two separate currents can be taken from the armature, one supplying alternating current and the other direct current; such a machine is called a *double current generator*.

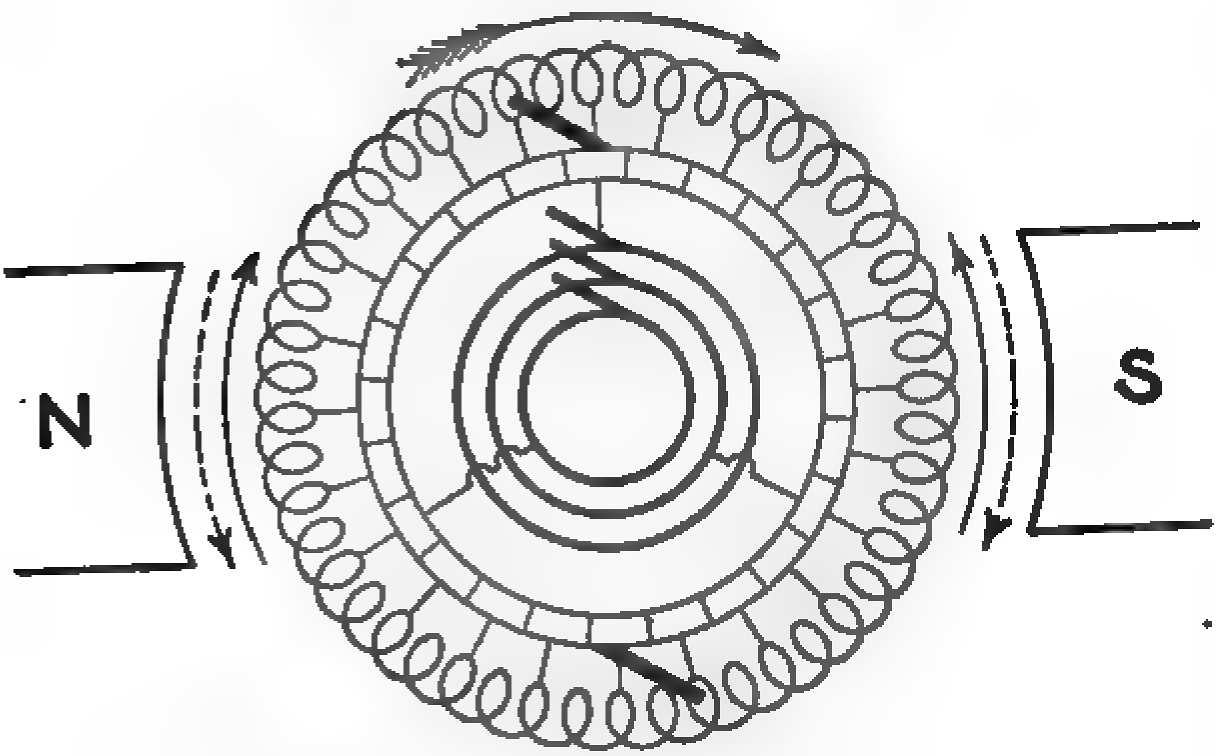
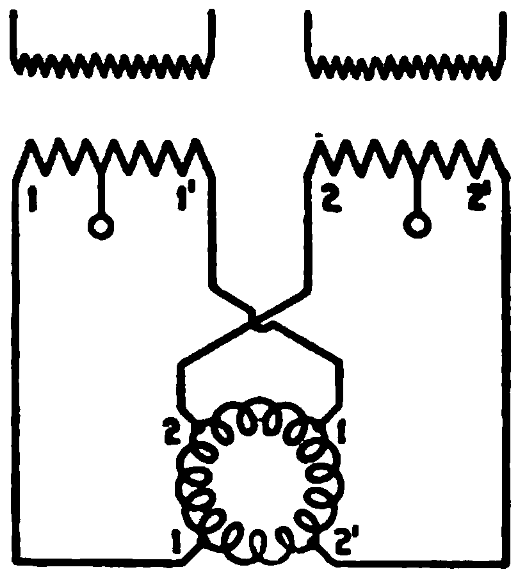


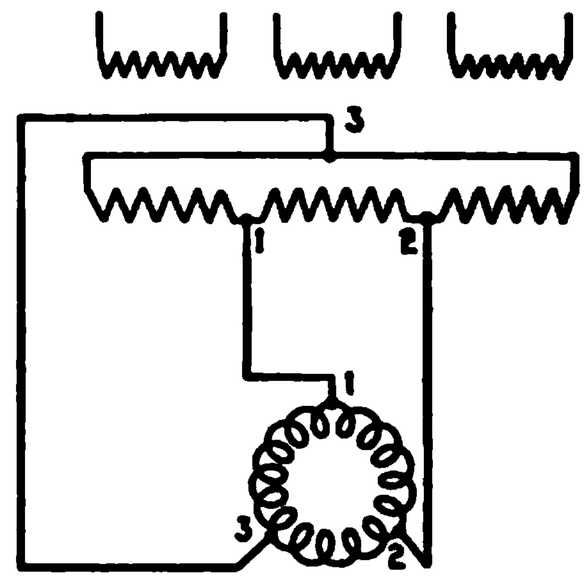
FIG. 2,036.—Diagram of three phase rotary converter. In this type, the winding is tapped at three points 120° distant from each other, and leads connected with the corresponding commutator segments.

4. If a direct current be sent in the armature coil through the commutator, the coil will begin to rotate as in a motor and an alternating current can be taken out of the collector rings. Such an arrangement is called an *inverted rotary converter*.

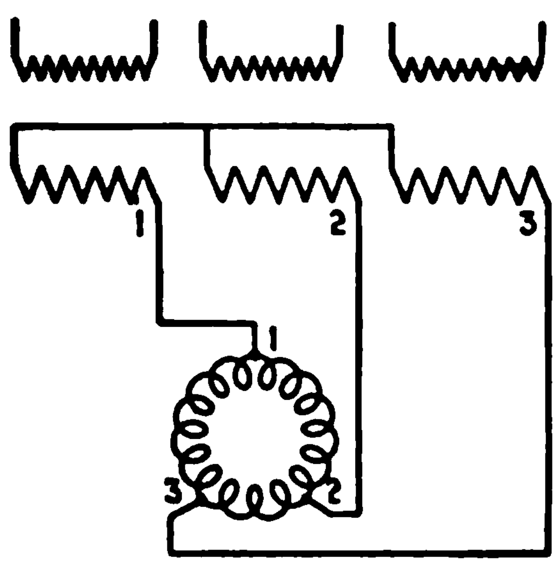
5. If the machine be brought up to synchronous speed by external means and then supplied with alternating current at the collector rings, then if the direction of the current through the armature coil and the pole piece have the proper magnetic relation, the coil will continue to rotate in synchronism with the current. A direct current can be taken from the commutator, and when used thus, the machine is called simply a *rotary converter*.



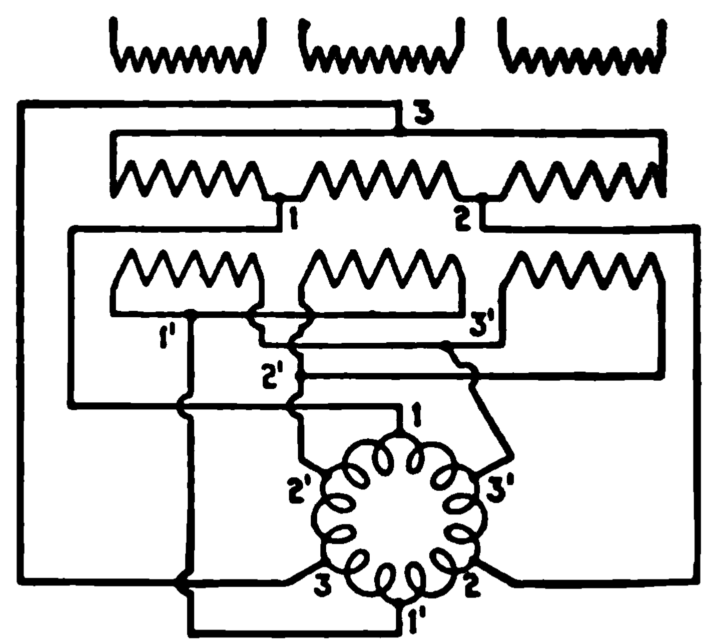
TWO PHASE



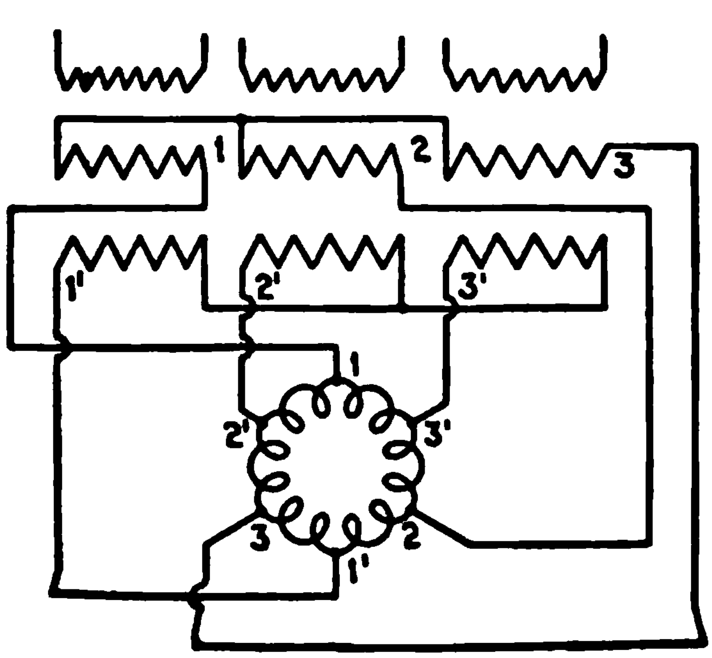
THREE PHASE Δ



THREE PHASE Y



SIX PHASE Δ



SIX PHASE Y

FIGS. 2,037 to 2,041. — Various rotary converter and transformer connections. Fig. 2,037 two phase connections; fig. 2,038 three phase delta connections; fig. 2,039 three phase Y or star connections; fig. 2,040 six phase delta connections; fig. 2,041 six phase Y connections.

Ques. What is the relation between the impressed alternating pressure and the direct pressure at the commutator?

Ans. The ratio between the impressed alternating pressure and the direct current pressure given out is theoretically constant, therefore, the direct pressure will always be as 1 to .707 for single phase converters or if the pressure of the machine used above indicate 100 volts at the direct current end, it will indicate 70.7 volts at the alternating current side of the circuit.

Ques. Name two different classes of converter.

Ans. Single phase and polyphase.

Ques. What is the advantage of polyphase converters?

Ans. In the majority of cases two or three phase converters are used on account of economy of copper in the transmission line.

Ques. How is the armature of a polyphase converter connected?

Ans. Similar to that of an alternator with either delta or Y connections.

Figs. 2,037 to 2,041 show various converter connections between the collector rings and commutator.

Fig. 2,037 indicates how the armature is tapped for two phase connections.

Fig. 2,038 shows three phase delta connections, and fig. 2,039 the three phase Y or star connections.

Six phase delta and Y connections are frequently used as shown in fig. 2,040 and fig. 2,041, both of which require two secondary coils in the transformer, one set of which is reversed, so as to supply the current in the proper direction.

Ques. With respect to the wave, what is the relation between the direct and alternating pressures?

Ans. The direct current voltage will be equal to the crest *of the pressure* wave while the alternating voltage will depend

Table of

Alternating Current and Voltage in Terms of Direct Current

(According to Steinmetz)

	DIRECT CURRENT	SINGLE PHASE	TWO PHASE	THREE PHASE	SIX PHASE	TWELVE PHASE	n PHASE
VOLTS BETWEEN COLLECTOR RING AND NEUTRAL POINT	1	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = 354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = 354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$
VOLTS BETWEEN ADJACENT COLLECTOR RINGS	1	$\frac{1}{\sqrt{2}} = .707$	$\frac{1}{2} = .5$	$\frac{\sqrt{3}}{2\sqrt{2}} = .612$	$\frac{1}{2\sqrt{2}} = .354$	.183	$\frac{\sin\frac{\pi}{n}}{\sqrt{2}}$
AMPERES PER LINE	1	$\sqrt{2} = 1.414$	$\frac{1}{\sqrt{2}} = .707$	$\frac{2\sqrt{2}}{3} = .943$	$\frac{\sqrt{2}}{3} = .472$	.236	$\frac{2\sqrt{2}}{n}$
AMPERES BETWEEN ADJACENT LINES	1	$\sqrt{2} = 1.414$	$\frac{1}{2} = .5$	$\frac{2\sqrt{2}}{3\sqrt{3}} = .545$	$\frac{\sqrt{2}}{3} = .472$	.455	$\frac{\sqrt{2}\sin\frac{\pi}{n}}{n}$

on the virtual value of the maximum voltage of the wave according to the connections employed.

In a single phase rotary, the value of the direct pressure is 1 to .707, therefore a rotary which must supply 600 volts direct current must be supplied by $600 \times .707 = 424$ volts alternating current. For three phase rotaries the ratio is 1 to .612, or in order to produce 600 volts direct current, $600 \times .612 = 367$ volts on the alternating current side of the rotary is required.

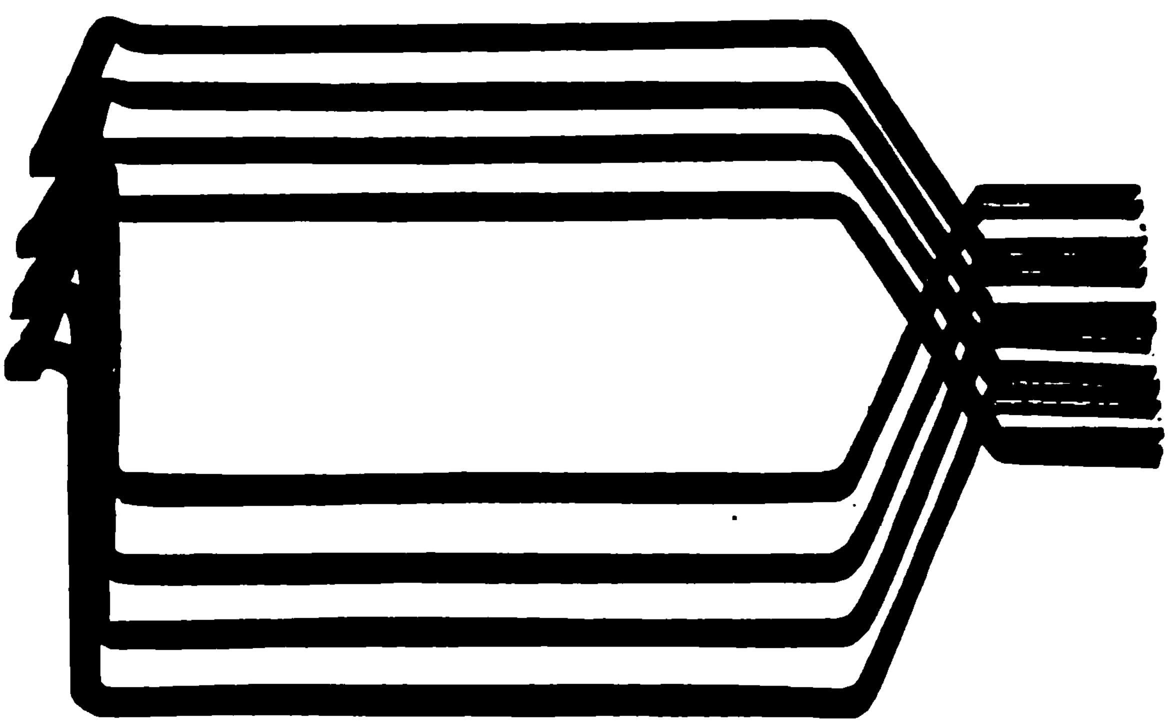


FIG. 2,042.—Westinghouse rotary converter armature coils. These are wound from bar copper and are interchangeable. The armature coils are heavily insulated to withstand the tests specified in the standardization rules of the American Institute of Electrical Engineers

Fig. 2,034 shows a complete diagram of the electrical connections. A single phase rotary is illustrated so as to simplify the wiring.

The table of Steinmetz on page 1,464 gives the values of the alternating volts and amperes in units of direct current.

Ques. How is the voltage of a rotary varied on the direct current side?

Ans. Pressure or potential regulators are put in the high tension alternating current circuit and may be regulated by small motors operated from the main switchboard or operated by hand.

Ques. What is the advantage of unity power factor for rotary converters?

Ans. It prevents overheating when the rotary is delivering its full load in watts.

Ques. What greatly influences the power factor of the high tension line?

Ans. The strength of the magnetic field.

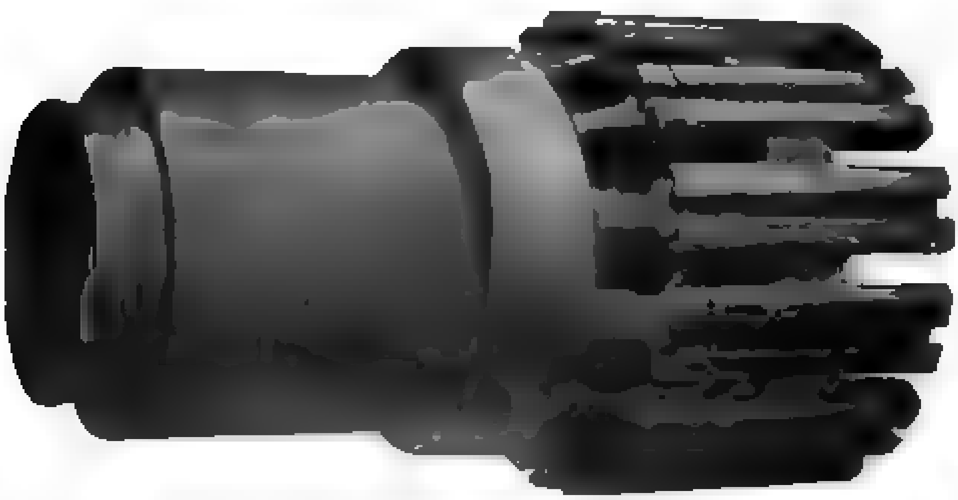


FIG. 2,043.—Westinghouse rotary converter armature spider. It is made of cast iron or cast steel. The dovetail grooves are machined in the feet or ends of the arms and in these slots the laminations forming the armature coil engage.

Ques. Does variation of the field strength materially affect the voltage?

Ans. No.

Since variation of the field strength does not materially affect the voltage, by adjusting the resistance in series with the magnetic circuit, the strength of the field can be changed and the power factor kept 1 or nearly 1 as different loads are thrown on and off the rotary.

Ques. What is the effect of a field too strong or too weak?

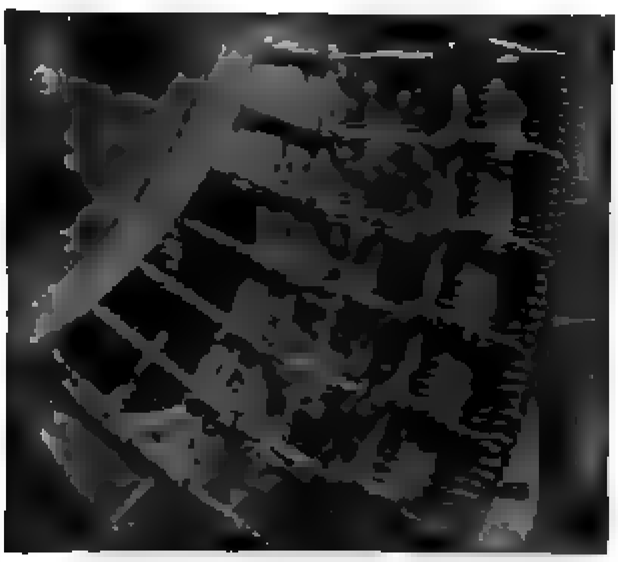
Ans. If too strong, a leading current is produced, and if too

ak, the current lags, both of which reduce the power factor d are objectionable.

Usually there is a power factor meter connected up in the main generating station and one also in the rotary substation, and it is the duty of the attendant at the substation to maintain the proper power factor.

Ques. What is the ordinary range of sizes of rotaries?

Ans. From 3 kw. to 3,000 kw.

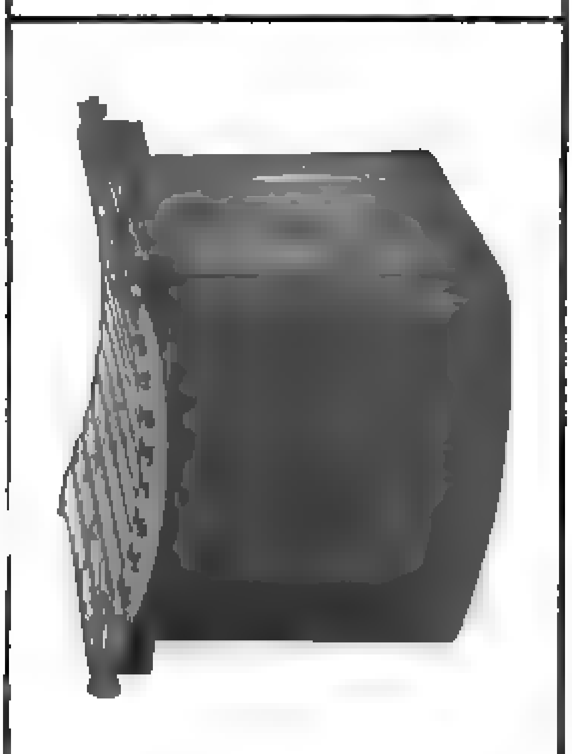


. 2,044.—Equalizer connections of Westinghouse rotary converter. The armature coils are cross connected at points of equal voltage and taps are led out from the winding at suitable points to the slip rings. This construction insures a uniform armature saturation below each pole piece and eliminates one cause of sparking at the commutator.

Ques. What is the general construction of a rotary nverter.

Ans. It is built similar to a dynamo with the addition of itable collector rings connected to the armature windings at ints having the proper phase relations.

Standard rotary converters have been developed for 25 and 60 cycles. The standard railway machines are compound wound, the series field being designed for a compounding of 600 volts at no load and full load when supplied from a source of constant pressure with not more than 10 per cent. resistance drop and with 20 to 30 per cent. reactance in the circuit. The large size machines are usually wound for six phase operation.



FIGS. 2,045 and 2,046. Westinghouse pole construction for converters. Fig. 2,045, pole without windings; fig 2,046, pole with windings. Poles are built up of sheet steel laminations held together with rivets. Projections on the inner ends of the poles form seats for the field coils and hold them in position. Copper dampers set in slots in the pole faces insure stable operation. Rotary converters for railway service are almost invariably compound wound. The series windings are formed of bare copper strap. The shunt windings are of insulated copper strap or wire. Spaces between coil turns and sections are provided for ventilation.

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large cities and similar installations where due to the larger number of car units demanding power, the load is more nearly constant.

Ratio of Conversion.—The relation between the alternating and direct current voltages varies slightly in different machines,

FIG. 2,047.—Westinghouse rotary converter brush rigging showing method of bracing the brushes. The brushes are supported by a rigid cast iron rocker ring which fits accurately in the frame. A handwheel worm and screw arrangement for shifting the brushes is provided Cast iron arms bolted to, but insulated from the rings, carry the rods on which the brush holders are mounted. Brush holders are of brass cast in one piece, of the sliding type and have braided copper shunts. Brush tension is adjustable.

due to differences in design. The best operating conditions exist when the desired direct current voltage is obtained with unity power factor at the converter terminals when loaded.

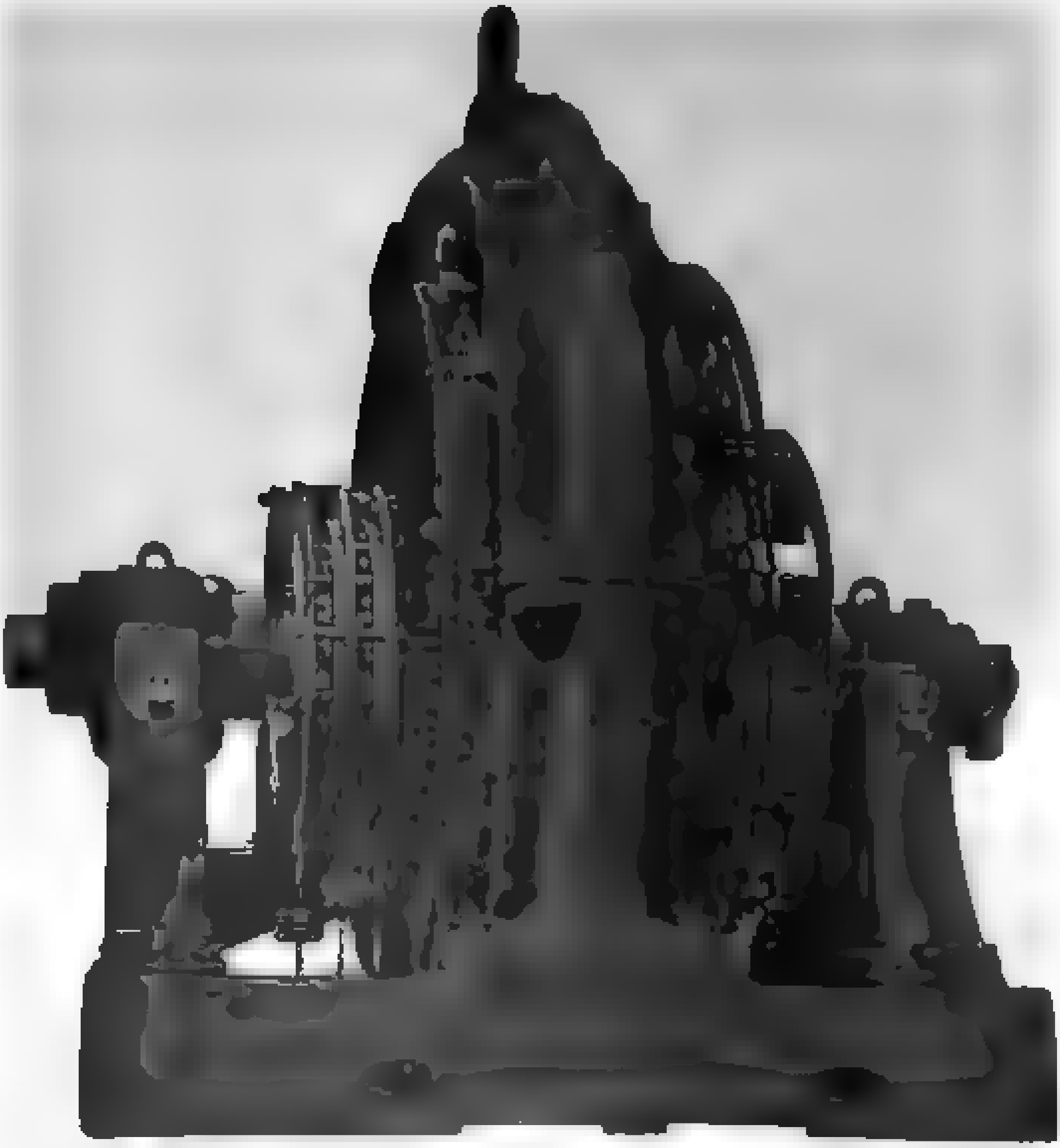


FIG. 2,048.—Westinghouse commutating pole rotary converter. The construction
are substantially the same as for the railway converter, with exception of the comm
poles. The application of commutating pole converters is particularly desirable
special requirements such as great overload capacity or large capacity and low
enable them to show to the greatest advantage. Commutating poles as applied to
converters fulfill the same functions as in the more familiar applications to dyna
motors. That is, the commutating pole insures sparkless commutation from
to heavy overloads with a fixed brush position. Brush shifting devices are not fu
on commutating pole converters. Commutating pole rotary converters for
service are normally arranged for automatic compounding which is effected by the
combination of series excitation and inductance between the generator and the
converter. This inductance is normally included in the transformer but in spec
may be partly in a transformer and partly in a separate reactance. It is possible
duce by this means a slight increase in the direct current voltage provided the
drop in the alternating current line be not excessive. Usually it is so arranged t
compounding that can be obtained is just sufficient to overcome the alternating
line voltage drop. The standard Westinghouse method of starting is alternating
self-starting. With this method of self-starting, the brushes of a commutating pole
converter must be lifted from the commutator during the starting operation to p
sparking. A mechanical device, as shown in fig. 2,050, is provided which accom
this. With direct current or motor starting a brush lifting device is not necessary.

Ques. Upon what does the ratio of conversion depend?

Ans. Upon the number of phases and method of connecting the windings.

For single phase or two phase machines it is 1 to .7; for three phase, 1 to .612, or six phase, 1 to .7 or 1 to .613 depending upon the kind of connection used for the transformer.

For example, a two phase rotary receiving alternating current at 426 volts will deliver direct current at 600 volts, while a three phase rotary receiving alternating current at 367 volts will deliver direct current at 600 volts.

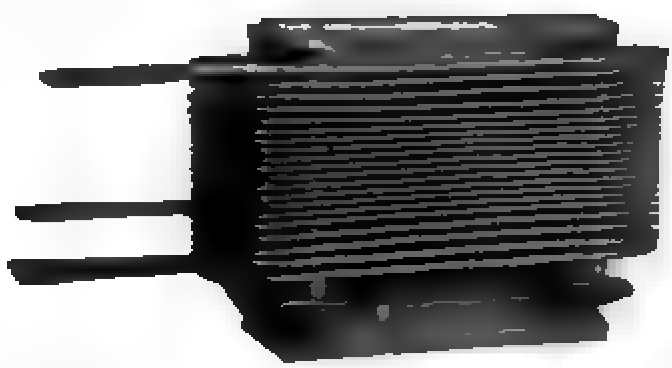


FIG. 2,049.—Commutating pole of Westinghouse commutating pole rotary converter. The commutating poles are similar in general construction to the main poles. The coils are of bare copper strap wound on edge. Ventilating spaces are provided between the pole and coil and between turns. The copper winding is bare except for a few turns at each end. Insulating bolts retain the turns in their proper position.

Ques. What difficulty would be encountered if other ratios of conversion than those given above were required?

Ans. An armature with a single winding could not be used.

It would be necessary to use a machine with two distinct armature windings or else a motor generator set.

Ques. What change in voltage is necessary between a converter and the alternator which furnishes the current?

Ans. The voltage must be reduced to the proper value by a step down transformer.

…lation.—As the ratio of the alternating to the …voltage of a converter is practically constant … provided to compensate for voltage variations …s of load in order to maintain the direct current …ant.

…several methods of doing this, as by:

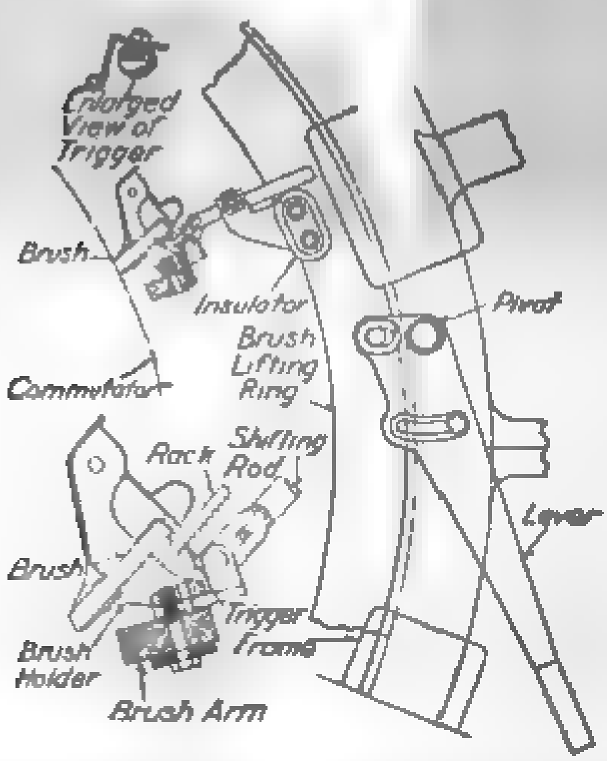
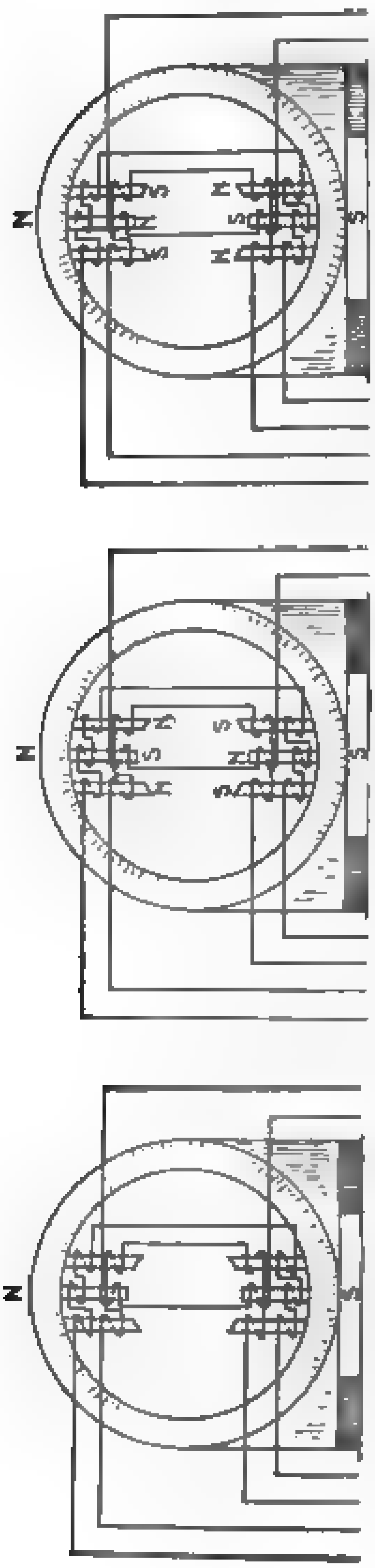


FIG. 2,050.—Westinghouse brush lifting device for commutating pole rotary converter. A rack is attached to each brush as shown. Into this rack the spring hinged lifting box of the raising device engages only when the lifting lever is shifted toward the raised position. The lifting arrangement is independent of the brushes during normal running, so it can in no way affect the operation of the machine. Each brush is merely raised and lowered within its own holder so the brush position or commutation is not altered.

1. Shifting the brushes (objectionable);
2. Split pole method;
3. Regulating pole method;
4. Reactance method;
5. "Multi-tap" transformer method.

Synchronous regulator.



Figs. 2,051 to 2,053.—Woodbridge split pole rotary converter. Each pole is split into three sections and provided with winding as indicated in fig. 2,051. When excited as in fig. 2,052, the commutator voltage is at its highest value; when excited as in fig. 2,053, the commutator voltage is low. The change in commutator voltage for constant collector ring voltage is in virtue of the property of rotary converters that the ratio of these two voltages is a function of the width of the pole arc.

Shifting the Brushes.—Were it not for the difficulties encountered, this would be a most convenient method of voltage regulation, since by this procedure the direct current voltage may be varied from maximum to zero. It is, however, not practical because of the excessive sparking produced when the brushes are shifted out of the neutral plane.

Split Pole Method.—In order to overcome the difficulty encountered in shifting the brushes the split pole method was devised by Woodbridge in which each field pole is split into two or three parts.

The effect of this is the same as shifting the brushes except that no sparking results.

The other part is arranged so that its excitation may be varied, thus shifting the resultant plane of the field with respect to the direct current brushes.

One of these parts is permanently excited and it produces near its edge the fringe of field necessary for sparkless commutation.

Regulating Pole Method.—As applied to the rota verter regulating poles fulfill the same functions as comm or interpoles (see page 385) on motors and dynamos, t they insure sparkless commutation from no load to heav loads with a fixed brush position.

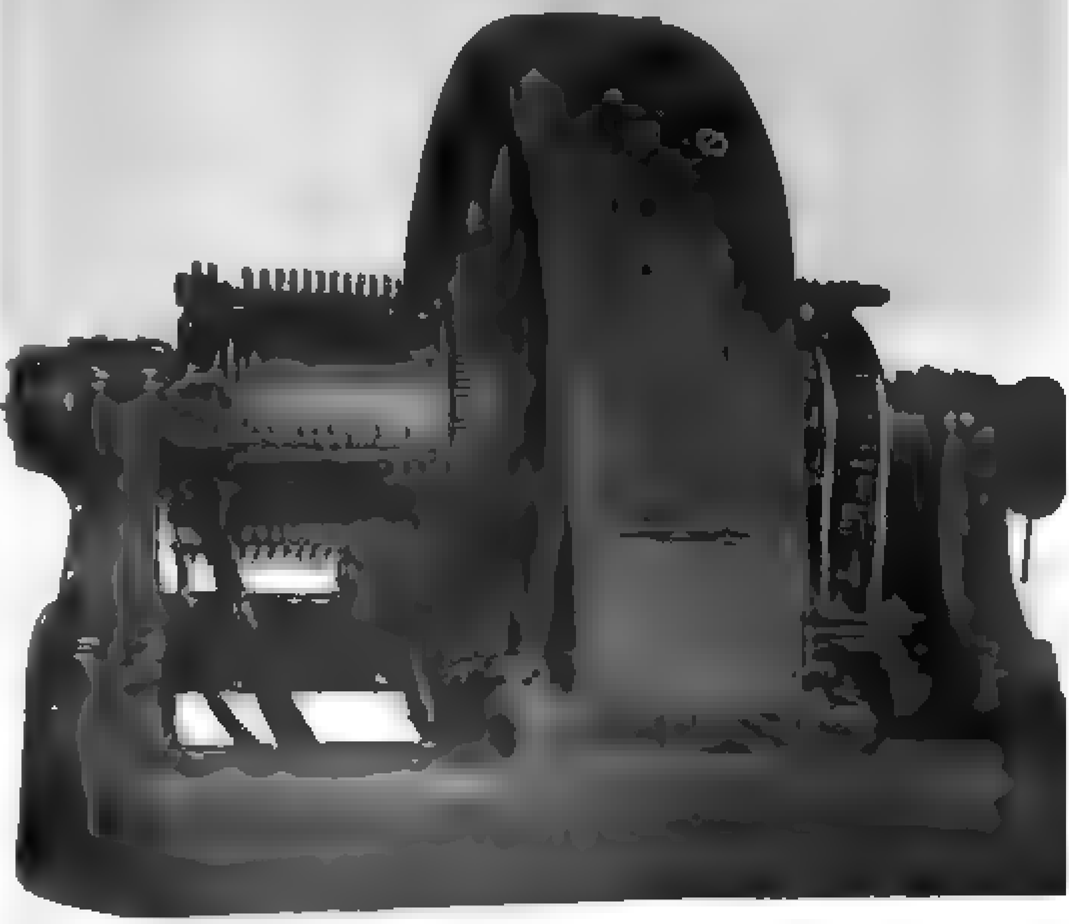


FIG. 2,054.—General Electric regulating pole rotary converter. The field structure into two parts, a main pole and a regulating pole. The ratio between the v the direct current and alternating current sides may be readily varied by v excitation of the regulating pole, the only auxiliary apparatus required be rheostat for controlling the exciting current. Where automatic regulation is machines may be provided with compound windings, or automatic field regul be used responsive to either voltage or current. These converters are adap variety of purposes where a variable conversion ratio is required, either to ma stant D. C. voltage with varying A. C. voltage or to vary the D. C. voltage a Converters may be operated inverted where it is required to furnish constant A. C. voltage from a D. C. source. Where converter and inverted converter are desired, an opposite direction of rotation is required for the inverted Converters of this type are built in capacities from 300 kw. up to 3,000 kw., structed to give a voltage range between 240 and 300 volts, to cover the usu circuit requirements. In design, they are similar to standard rotary conver the exception that the regulating poles are located next to the main pole pi slightly different form of pole piece bridge is used for the main poles, in orde the auxiliary poles to be readily removed or assembled.

The regulating poles are used in order to vary the ratio between the alternating current collector rings and the direct current side without the use of auxiliary apparatus such as induction regulators or dial switches which involve complicated connections and many additional wires. The regulating poles are arranged with suitable connection so that the current through them can be raised, lowered or reversed.

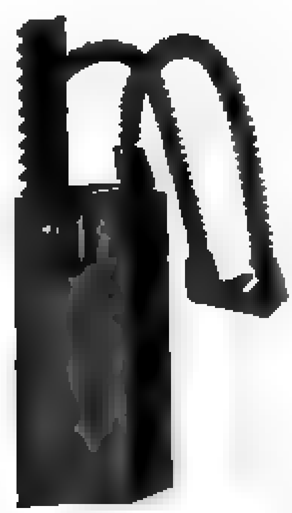


FIG. 2,055.—Detail of Westinghouse commutating pole rotary converter brush, showing rack. The brush lifting mechanism and its operation is explained in fig. 2,060.

The characteristics of the regulating pole converter being novel, a detailed explanation of the principles involved is given to facilitate a clear understanding of its operation.

Consider a machine with a field structure as shown in fig. 2,056 resembling in appearance a machine with commutating poles, but with the brushes so set that one of the regulating poles adds its flux to that of one main pole, cutting the inductors between two direct current brushes. The regulating pole is shown with a width equal to 20 per cent. of that of the main pole.

To obtain definite figures, it will be assumed that the machine at normal speed, with the main poles excited to normal density, but with no excitation on the regulating poles, gives 250 volts direct current pressure. Then with each regulating pole excited to the same density

as the main poles, and with a polarity corresponding to that of the main pole in the same section between brushes, the direct current pressure will rise to 300 volts at the same speed, since the total flux cutting the inductors in one direction between brushes has been increased 20 per cent.

If, on the other hand, the excitation of the regulating poles be reversed and increased to the same density as that of the main poles, the direct current pressure will fall to 200 volts, since in this case the regulating poles give a reverse pressure, that is, a pressure opposing that generated by the main poles.

Now, if the machine be equipped with collector rings, that is, if it

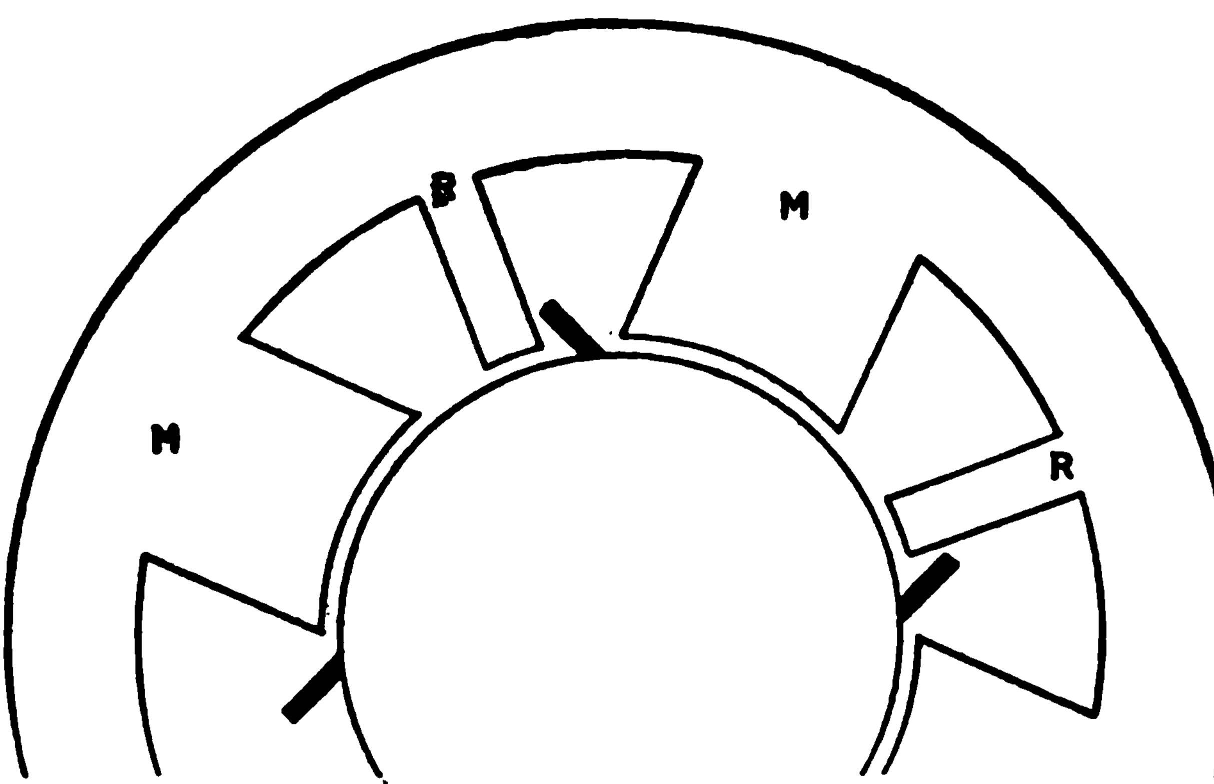


FIG. 2,056.—Diagram of field of regulating pole converter illustrating principles explained in the accompanying text.

be a converter, this method of varying the direct current voltage from 200 to 300 volts does not give nearly as great a variation of the alternating current voltage; in fact, the latter voltage will be the same when delivering 200 volts as when delivering 300 volts direct current pressure, if the field excitation be the same.

This may be seen by reference to fig. 2,057, which is a diagram of the alternating current voltage developed in the armature windings by the two sets of poles.

The horizontal line OA represents the alternating current voltage

NOTE.—In the Burnham split pole rotary converter, each pole is divided into only two sections, one larger than the other. A main shunt winding is arranged on the large sections, and a winding for providing the voltage regulation is placed on the other section. When the current is sent through this latter winding in one direction the voltage is raised, when in the other direction the voltage is lowered.

generated by the main poles, alone, with the regulating poles unexcited, that is, when delivering 250 volts direct current pressure.

For a six phase converter OA measures about 180 volts diametrically, that is, between electrically opposite collector rings.

If now the regulating poles be excited to full strength, to bring the direct current pressure up to 300 volts, the alternating current voltage generated by the regulating poles will be 90 degrees out of phase with that generated by the main poles (since they are placed midway between the main poles), and will be about 40 volts as shown by the line AB.

The resultant alternating current volts across the collector rings will be represented by the line OB with a value equal to 184.

Again. if the regulating poles be reversed at full strength, to cut the direct current pressure down to 200 volts, the alternating current voltage

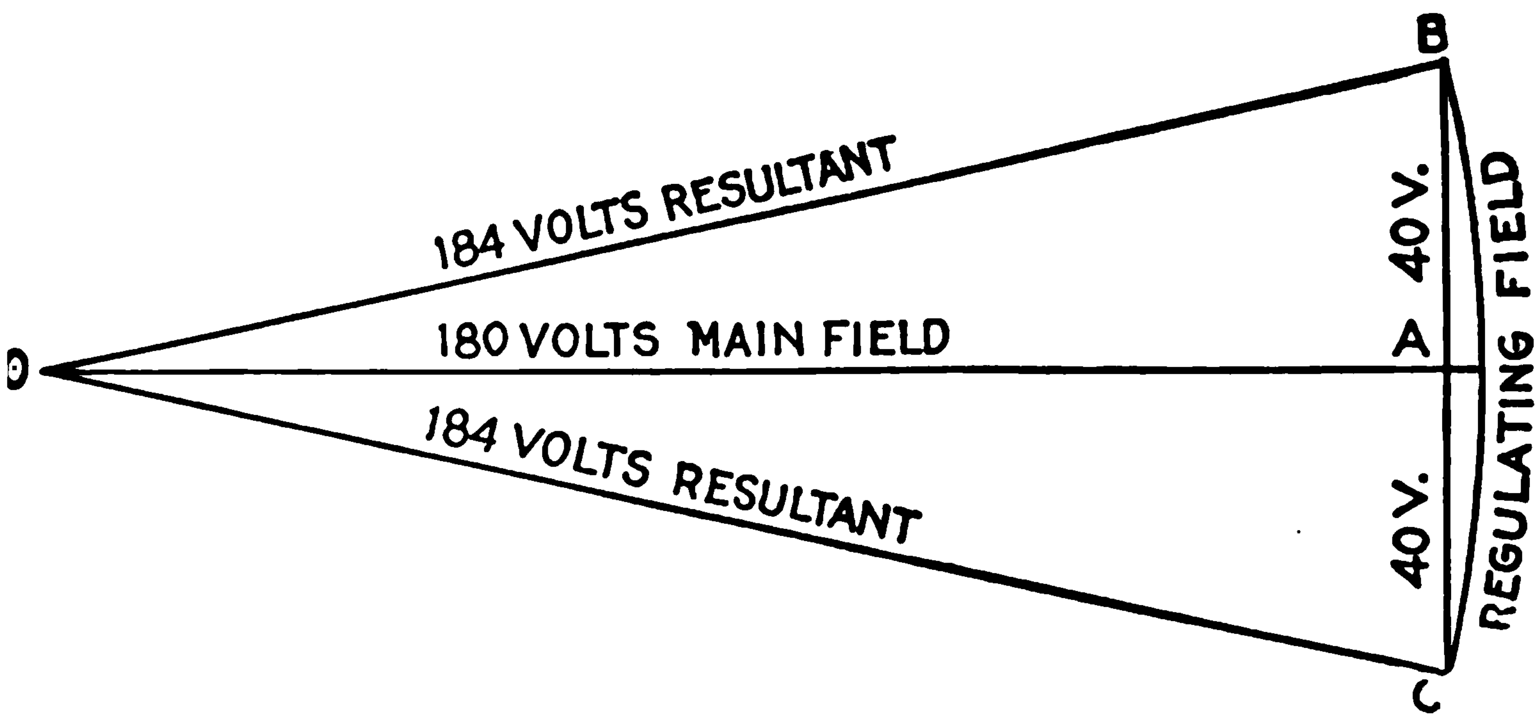
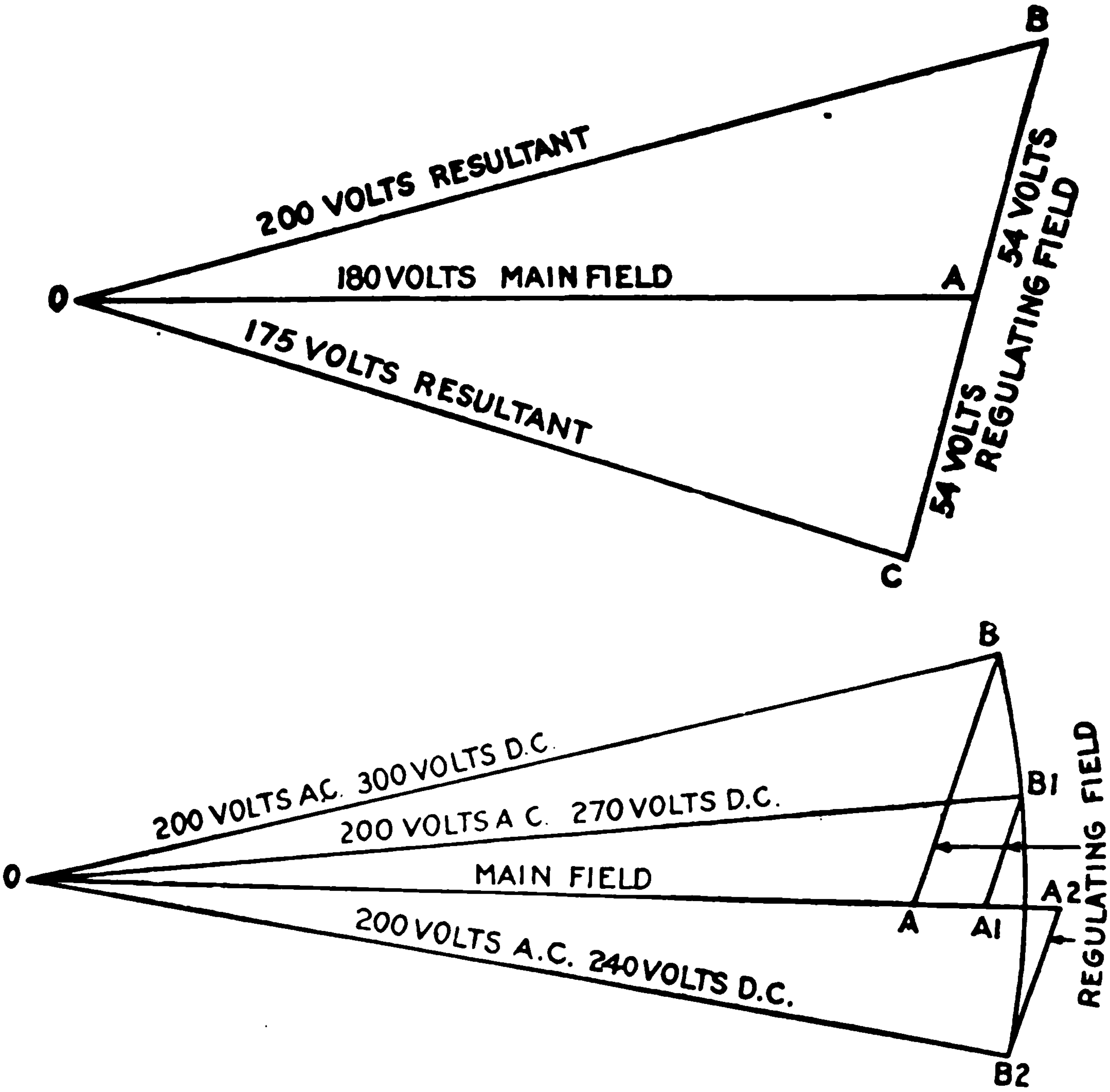


FIG. 2,057.—Voltage diagram for regulating pole converter illustrating principles explained in the accompanying text.

of the main and regulating poles will be OA and AC respectively, giving the resultant OC equal to OB with a value of 184 volts. Accordingly, the direct current pressure may be either 200 or 300 volts with the same alternating current pressure, and if the main field be kept constant, the direct current pressure may range between 200 or 300 volts, while the alternating current pressure varies only between 180 and 184 volts.

The alternating current pressure can be kept constant through the full range of direct current voltage by changing the main field so as always to give an equal and opposite flux change to that of the regulating field. A constant total flux may thus be obtained equal to the radius of the arc BC, fig. 2,057. In this case the line OA, representing the main field strength, will equal OB when the regulating field is not excited, and 250 volts can only be obtained at this adjustment.

This method of operation gives unity power factor with a constant impressed pressure of 184 volts alternating current with a range of direct current voltage from 200 to 300 volts.



Figs. 2,058 and 2,059.—Diagrams illustrating the effect on the alternating current voltage due to varying the regulating field strength (of a machine proportioned according to fig. 2,060), from a density equal to that in the main poles to the same density reversed, the main field strength remaining constant. The D. C. voltage in this case varies from 30 per cent. above that produced by the main field alone to 30 per cent. below, or from 325 to 175 volts, while the A. C. voltage varies only from 200 to 175 volts. To keep the A. C. voltage constant with such a machine the main field must be strengthened as the regulating field is weakened or reversed to reduce the D. C. voltage. This strengthening increases the core loss particularly on low direct current voltages, which however, are rarely required, hence a machine proportioned as in fig. 2,060, would not be operated through so wide a range as 175 to 325 volts. Assume that the range is 240 to 300 volts, and that at the highest voltage, both main and regulating fields have the same density, presenting to the armature practically one continuous pole face of uniform flux intensity. The diagram of A. C. component voltages to give constant A. C. resultant voltage across the rings for the case, is shown in fig. 2,059. At 300 volts D. C., the main field produces an A. C. voltage OA, and the regulating field, a voltage AB, with a resultant OB, equal to about 200 volts A. C. At 270 volts D. C., the main field produces an A. C. voltage OA, and a regulating field voltage AB, giving a resultant A. C. voltage OB, equal to 200 volts. Similarly, at 240 volts D. C., the main field produces an A. C. voltage OA, and the regulating field (now reversed) produces the reverse voltage AB, giving the resultant OB again equal to 200 volts. It will be noted that, theoretically the main field strength *must be increased* about 15 per cent. above its value at 300 volts D. C. in order to *keep the D. C. voltage at 250 volts.*

[redacted]

Ques. Where should the regulating poles be located for best results?

Ans. A better construction is obtained by placing them closer to the corresponding main pole, as in fig. 2,060, than when spaced midway between the main poles as in fig. 2,056.

Ques. When the regulating poles are spaced as in fig. 2,060, what is the effect on the direct current voltage?

Ans. The effect is the same as for the midway position (fig. 2,056) except for magnetic leakage from the main poles to

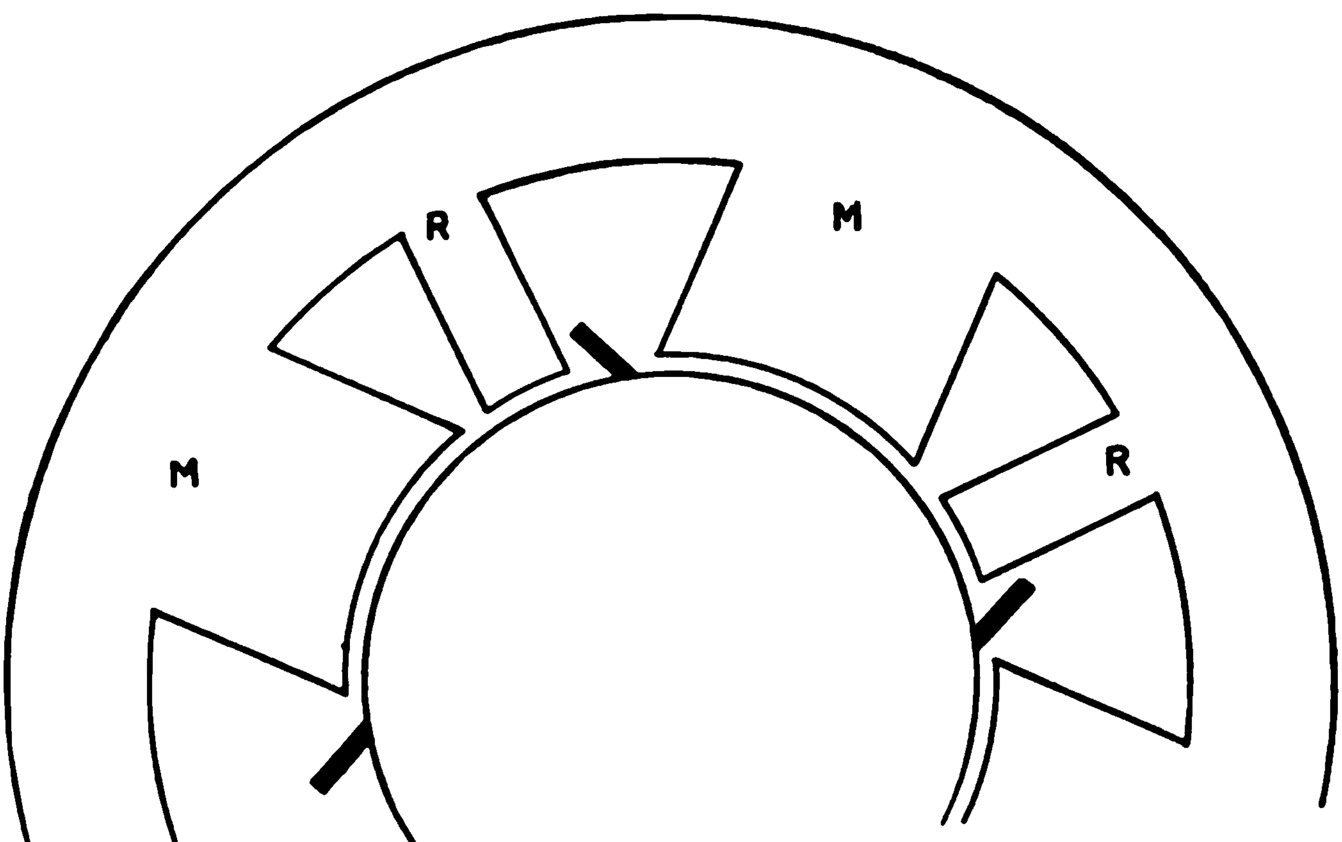


FIG. 2,060.—Diagram illustrating placement of regulating poles. In practice machines are not built as indicated diagrammatically in fig. 2,056, that is, with regulating poles spaced midway between the main poles, because a better construction is obtained by placing the regulating pole closer to the corresponding main pole, as shown above.

the regulating poles when the latter is opposed to the former, that is, when the direct current voltage is being depressed.

Ques. What is the effect on the alternating current voltage?

Ans. It is somewhat altered as explained in figs. 2,058 and 2,059.

Reactance Method.—This consists in inserti in the supply circuit and running the *load* curr few turns around the field cores. This method called *compounding*, and as it is automatic it is where there is a rapidly fluctuating load.

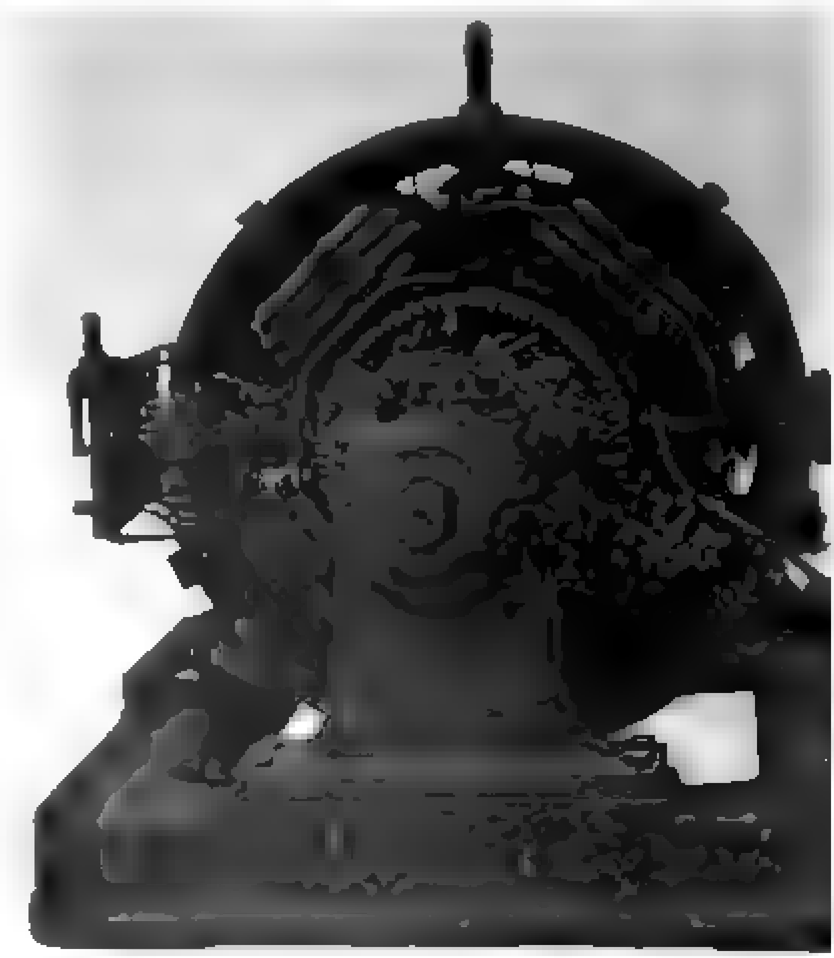


FIG. 2,061.—Westinghouse 300 kw., 1,600 volt, three phase, 25 cycle, rotary converter. The illustration shows clearly the commutating, the relative sizes, also arrangement of the terminal connections.

If a lagging current be passed through an in collector ring voltage will be lowered, but will be of a leading current. The degree of excitation change in the phase of the current to the convert tion, in turn, being regulated by the load current.

ies inductance, the effect of the series coils on the field converter is quite similar to that of the compounding of inary railway dynamo.

l-tap Transformer Method.—The employment of a ratio step down transformer for voltage regulation is a omatic method of control and, accordingly, is not de- except in cases where the load is fairly constant over able periods of time. It requires no special explanation.

—Mechanical oscillator and speed limit device of Westinghouse commutating pole converter. It automatically prevents the armature of the converter remaining position and thus not allowing brushes to wear grooves in both commutator and r rings. The oscillator is a self-contained device carried at one end of the shaft. erating parts consist of a hardened steel ball and a steel plate with a circular ball acked by a spring. The machine is so installed with a slight inclination toward l carrying the oscillator. As the armature revolves the ball is carried upward and to the convergence of the steel race and shaft face, the spring is compressed. The n of the spring forces the armature away from its natural position and allows the drop back to the lowest point of the race.

hronous Booster Method.—This consists of combining e converter a revolving armature alternator having the umber of poles.

Ques. How is the winding of the booster alternator armature connected?

Ans. It is connected in series with the input circuits on the converter.

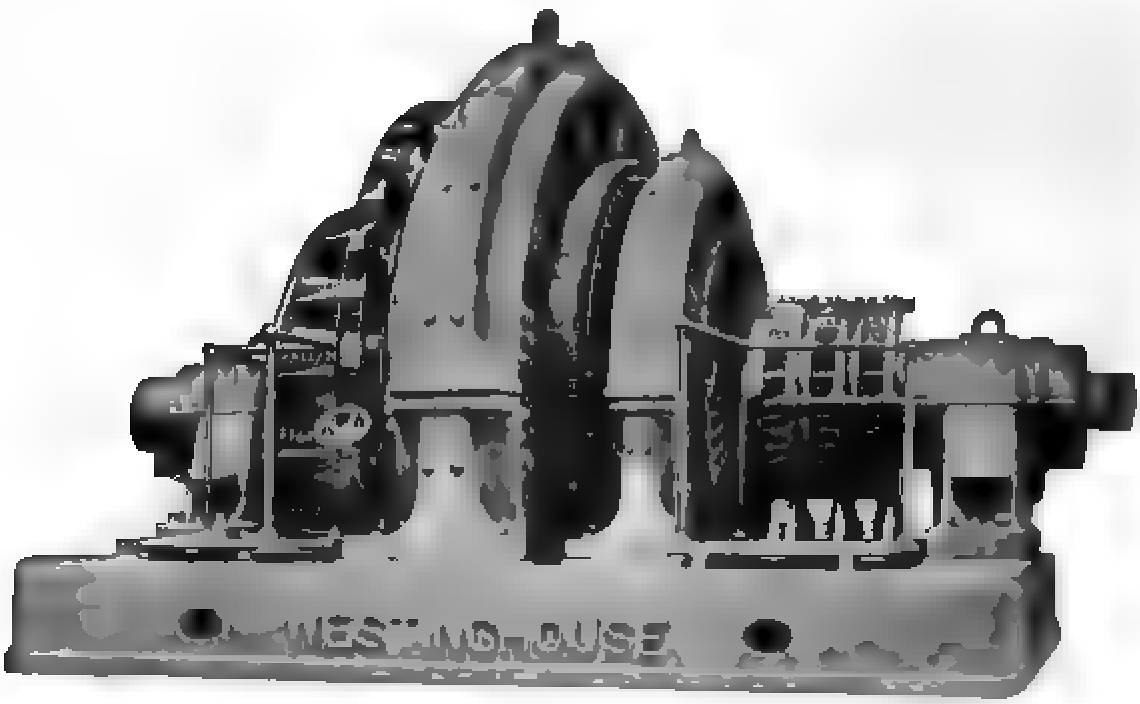


FIG. 2,063.—Westinghouse 2,000 kw., 270 volt, direct current, 6 phase, 167 R.P.M., synchronous booster rotary converter, having a voltage range from 230 to 310 volts. It consists of a standard rotary converter in combination with a revolving armature alternator mounted on the same shaft with the rotary converter and having the same number of poles. By varying the field excitation of the alternator, the alternating current voltage impressed on the rotary converter can be increased or decreased as desired. The direct current voltage delivered by the converter is thereby varied accordingly. The principle of operation of the booster converter is therefore very simple and easily understood. It is simply a combination of two standard pieces of electrical apparatus, accordingly there are incorporated in it no details of construction essentially different from those encountered in standard rotary converters and alternators. The only novelty is in their combination. The frames may be supported either from the rotary converter frame, as in the small units, or from the bed plate, as in the larger ones. A synchronous booster converter can be built, if necessary, with a vertical shaft to satisfy special floor space and head room requirements.

Ques. How are the field windings connected?

Ans. They are either fed with current regulated by means of a motor operated field circuit rheostat, or joined in series with the commutator leads of the converter.

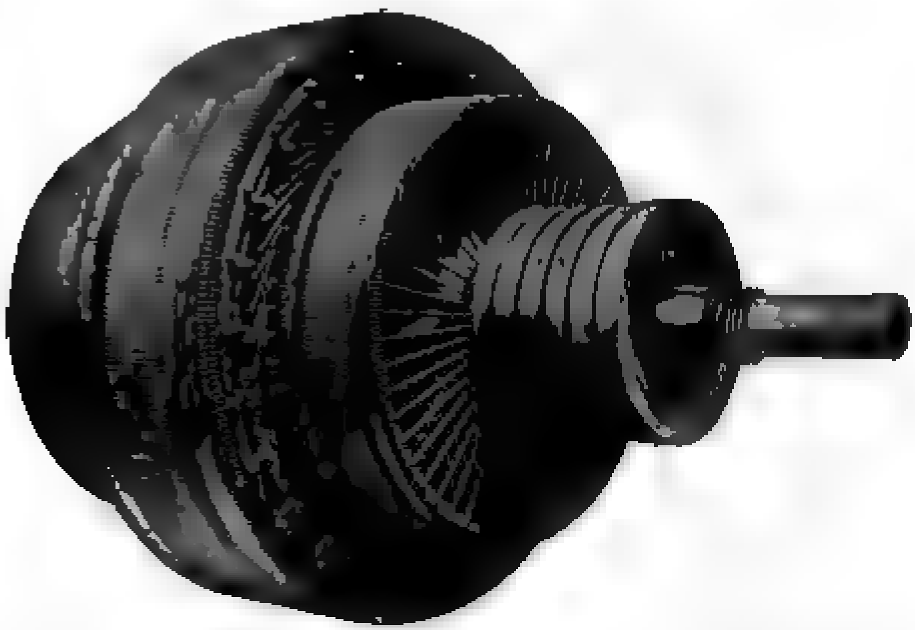


FIG. 2,064.—Armature of Westinghouse synchronous booster converter. Heavy cast yokes form the frames. They are proportioned to rigidly support the laminated steel field poles. The poles are fastened to the frame with through bolts. A lifting hook is provided on all frames. The bed plates are in one piece for the smaller machines but two piece bed plates are used for the larger ones. The bearings are ring oiling and have babbitt wearing surfaces that are renewable.

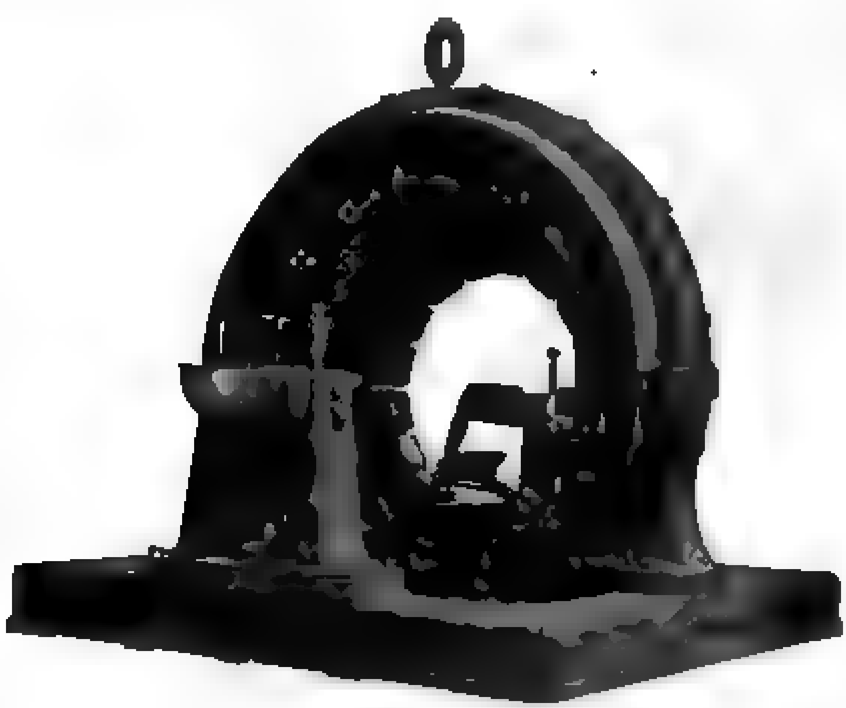


FIG. 2,065.—Westinghouse field frames and bearings for synchronous booster rotary converter. The frames consist of heavy cast yokes. The poles are fastened to the frames with through bolts. The bed plate is in one piece for the small machines and in two pieces for the large ones.

[redacted]

Ques. For what service is the synchronous booster method desirable?

Ans. For any application where a relatively wide variation in direct current voltage is necessary.

It is particularly desirable for serving incandescent lighting systems where considerable voltage variation is required for the compensation of drop in long feeders, for operation in parallel with storage batteries and for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

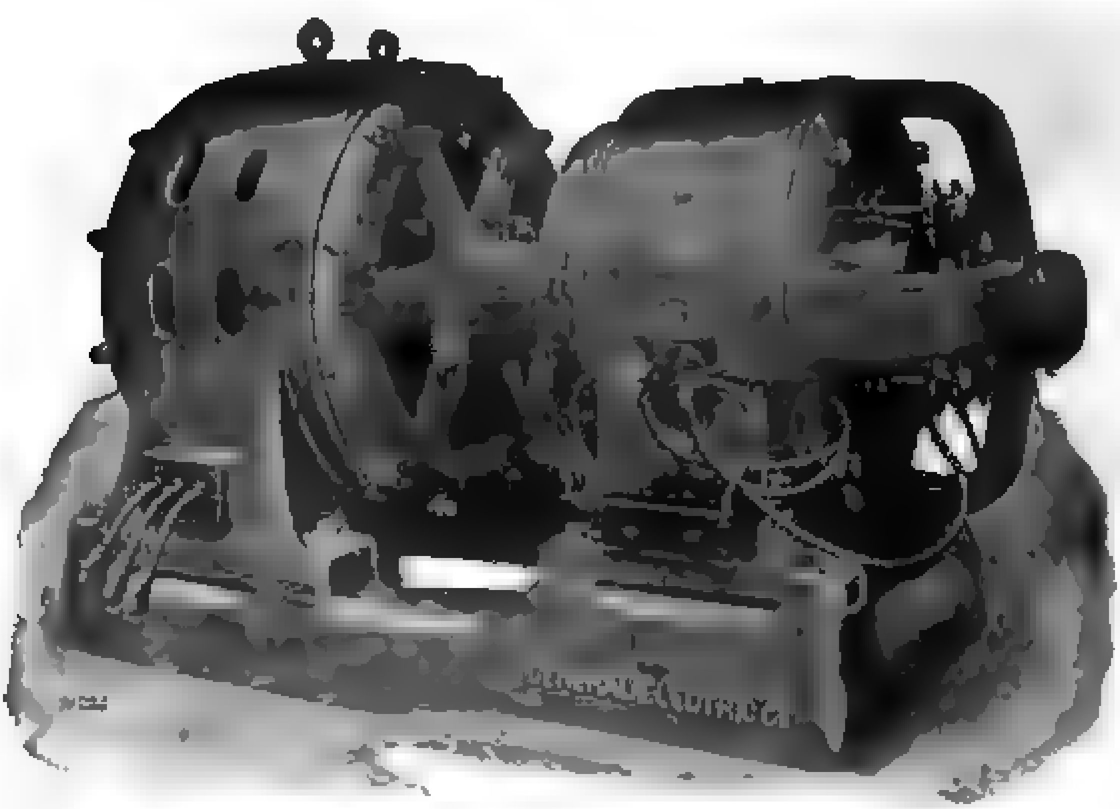


FIG. 2,068.—General Electric motor generator set consisting of 2,300 volt synchronous motor and 550 volt dynamo.

Motor Generator Sets.—The ordinary rotary converter is the most economical machine for converting alternating currents into direct currents, and where slight variations in the direct current voltage is necessary, they are mostly used on account of their high efficiency, and because they are compact.

FIG. 2,087.—General Electric motor generator set consisting of 220 volt induction motor and 125 volt dynamo.

In many central stations where they supply a great variety of apparatus, the motor generator sets are employed as the generator is independent of the alternating current line voltage and any degree of voltage regulation can be performed.

Motor Generator Combinations.—The following combinations of motor generators are made and used to suit local conditions:

Synchronous motor..............dynamo
Induction motor.................dynamo
Direct current motor............dynamo
Direct current motor............alternator
Synchronous motor..............alternator
Induction motor.................alternator

Standard practice has adopted high tension alternating current for transmission systems, but direct current distribution

FIG. 2,068.—General Electric motor-generator set, as installed for the Cleveland Electric Illuminating Company, Cleveland, Ohio. It consists of 11,431 volt motor and 275 volt generator. Speed, 360 revolutions per minute.

is very frequently used. This is particularly true where alternating current apparatus has been introduced in old direct current lighting systems.

The synchronous motor or the induction motor connected to a generator stands next in importance to the rotary converter because it is easy to operate and the pressure may be changed by a rheostat placed in the field circuit of the generator.

The line wires carrying full voltage can usually be connected direct to the motor and thus do away with the necessary step-down transformer required by the rotary.

Ques. What is the behavior of a rotary converter when hunting?

Ans. It is liable to flash over at the direct current brushes, which is common in high frequency converters where there are a great number of poles and the brushes are necessarily spaced close together around the commutator.

Ques. Is this fault so pronounced with motor generator sets?

Ans. The motor generator operating on a high frequency circuit, the generator can be designed with a few poles and the brushes set far apart which will greatly reduce the chance of flashing over.

A synchronous motor will drive a generator at a constant speed during changes in load on it, and by having a field regulating resistance it can be used to improve the power factor of the system.

When an induction motor is used its speed drops off slowly as the load comes on the generator, and it is necessary to regulate the voltage of the generator by means of a field rheostat, or compound wound machines may be used.

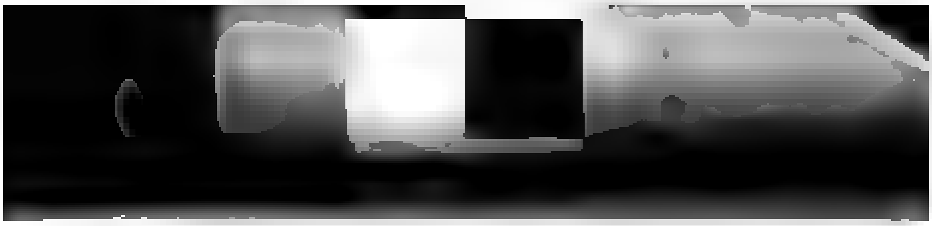
While an induction motor requires no separate excitation of the field magnets like the synchronous motor, its effect on the power factor of the system is undesirable.

Although it is seldom necessary to convert direct current to alternating, such an arrangement of a direct current motor driving an alternator is often justified in place of an inverted rotary converter, as in this case the alternating current voltage can be changed independent of the direct current voltage.

The racing of an inverted rotary under a heavy inductive load or short circuit does not take place in motor generator set mentioned above.

FIG. 2,069.—General Electric frequency changer set, consisting of a 11,000 volt synchronous motor with direct connected exciter and a 2,300 volt alternator.

Frequency Changing Sets.—A frequency of 25 cycles is generally used on railway work and in large cities using the Edison three wire system, and as a 25 cycle current is not desirable for electric lighting it is necessary to change it to 60 cycles by *means of* a frequency changer shown in fig. 2,069 for distribution *in the* outlying districts.



The two machines in this combination are of the same construction, only the synchronous motor would have eight poles and have the 25 cycle current passing through it, while the generator would have 20 poles and produce 62½ cycles per second at 300 revolutions per minute. By supplying the motor with 24 cycles, the generator would produce 60 cycles.

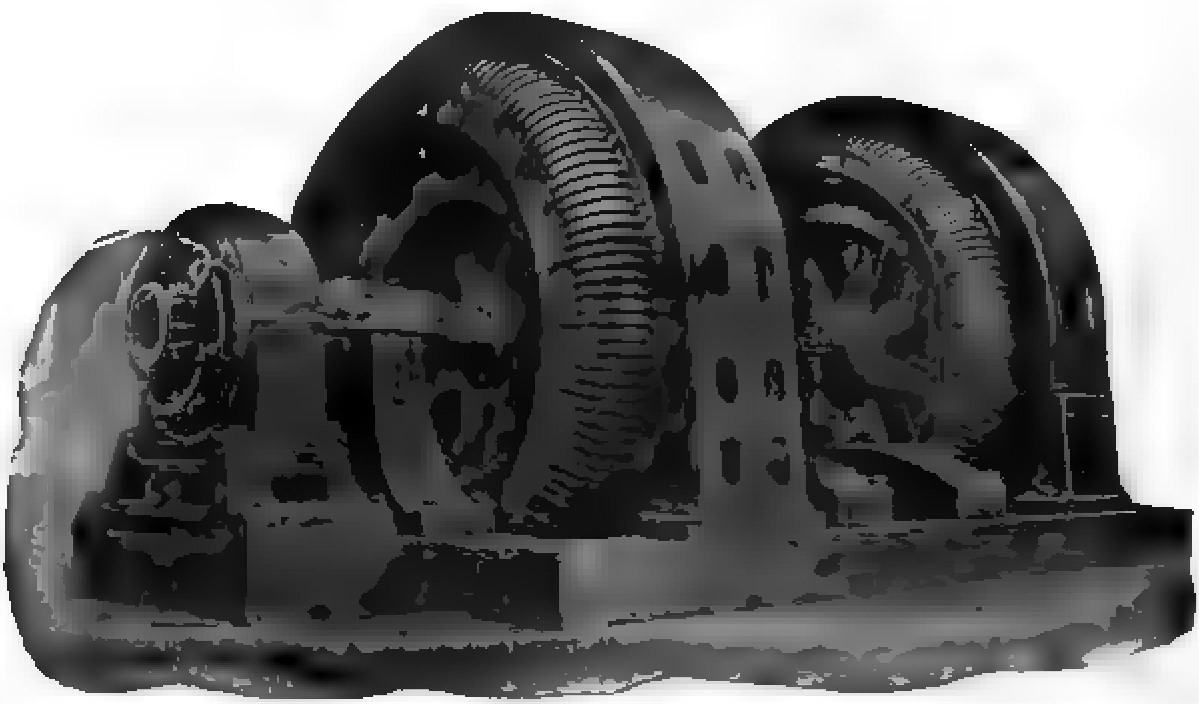


FIG. 2,070. General Electric four unit frequency changer set consisting of a 11,000 volt synchronous motor, 13,200 volt alternator, 250 volt exciter, and 440 volt starting induction motor. Where parallel operation is required between synchronous motor driven frequency changers, a mechanical adjustment is necessary between the fields or armatures of the alternator and motor to obtain equal division of the load. The adjustment can be obtained by shifting the keyway, or by special cradle construction. In the latter method, one machine is bolted to a cradle fastened to the base. By taking out the bolts, the frame can be turned around through a small angle relatively to the cradle and therefore to the armature frame of the other machine, when the bolts can be replaced.

It will be seen from the figure that the separate exciter is fastened on the base plate and has its armature directly connected to the shaft.

Parallel Operation of Frequency Changers.—It is very difficult to construct two or more frequency changers and join them to synchronous motors so that the current wave of one

machine will be in phase with the other, since the speed of the motor will depend on the frequency of the line and be independent of the load thrown on it.

When alternators are run in parallel, if one machine lag behind, the other carries the load with the result that the lightly loaded machine will speed up and get in step with the other, or

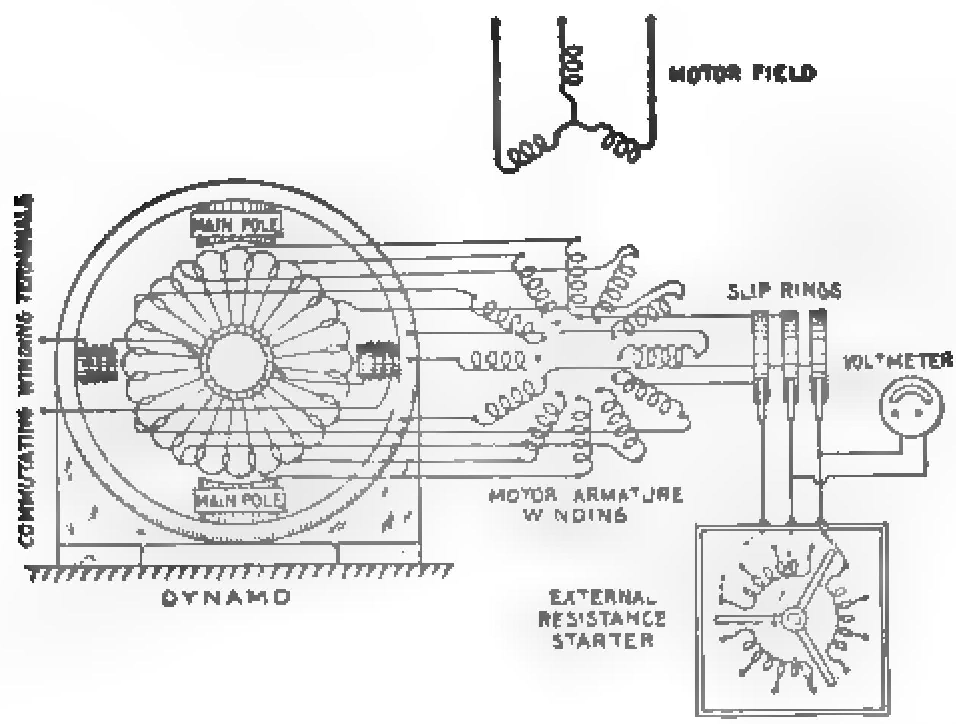


FIG. 2,071.—Diagram of "Cascade" motor generator set or motor converter, as it is called in England where it is used extensively for electric railway work. In the diagram of motor armature winding, some of the connections are omitted for simplicity. The windings are Y connected, and as they are fed by wires joined to the slip rings at the right and center, the rest of the power passes to the converter windings back to rotor winding and out to the slip rings so that part of the power enters the rotor and part through the converter.

in other words a synchronizing current will flow between the two alternators and tend to keep them in proper relation with respect to phase and load.

Cascade Converter.—This piece of apparatus was introduced by Arnold and La Cour. Briefly, it consists of a combination of an induction motor having a wound armature and

[redacted]

a dynamo, the armatures being placed on the same shaft. The windings are joined in cascade, that is, in series with those of the armature of the induction motor. The line supplies three phase currents at high voltage direct to the field of the induction

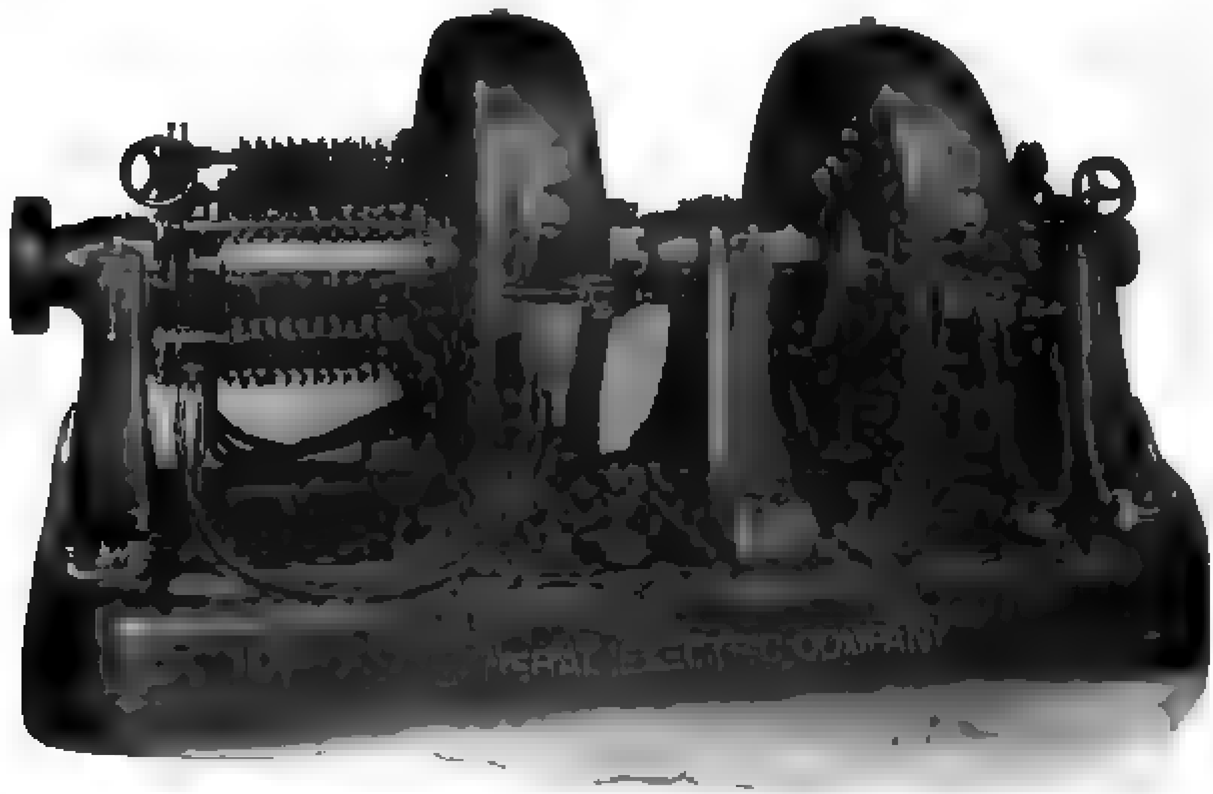


Fig. 2,072.—General Electric shunt wound booster set. Sets of this class are used in railway stations to raise the pressure of the feeders extending to distant points of the system, for storage battery charging and regulation, and in connection with the Edison three wire lighting system. The design of the various sets is closely dependent upon their application. Booster sets are constructed in either series or shunt wound types and they may be arranged for either automatic or hand regulation, depending on the nature of the service required. Where there are a number of lighting feeders connected and run at full load for only a short time each day it will generally be economical to install boosters rather than to invest in additional feeder copper. It is important, however, to consider each case where the question of installing a booster arises, as a separate problem, and to determine if the value of the power lost represents an amount lower than the interest charge on the extra copper necessary to deliver the same voltage without the use of a booster.

motor and drives it, generating in it currents at a lower voltage depending on the ratio of the windings.

Part of the current thus generated in the armature passes into the armature of the dynamo and is converted by the

commutator into direct current as in a rotar[illegible] also increased by the current induced in t[illegible] dynamo armature.

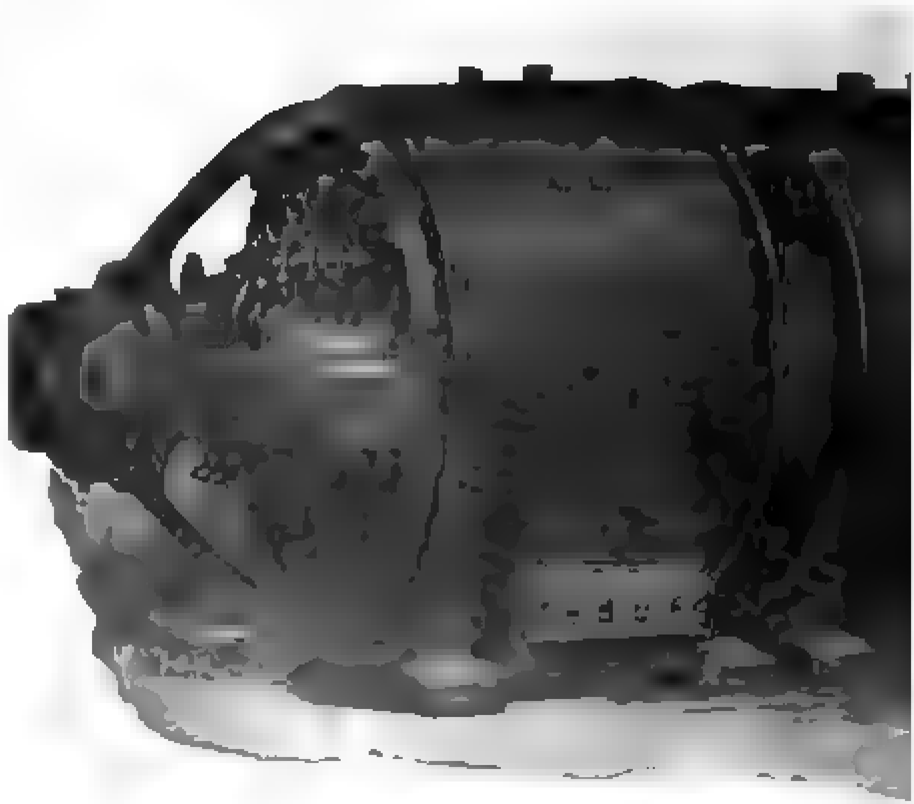
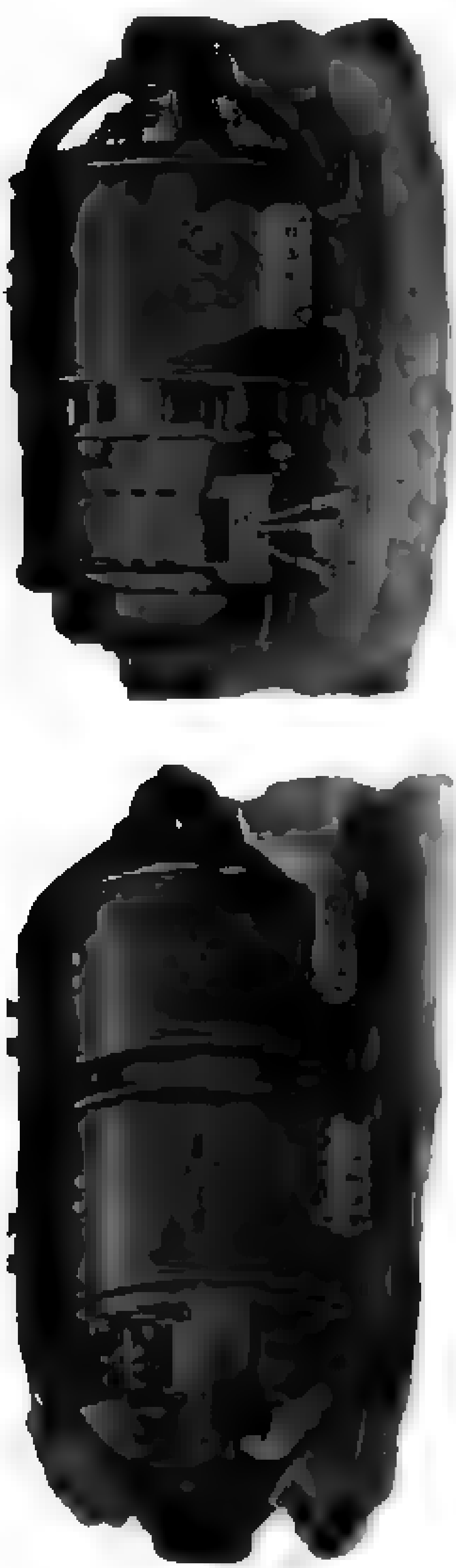


FIG. 2,073.—General [illegible] 0.5 kw. 1,000 R.P.M. balancer set. current [illegible] which it is composed may generator, [illegible] interconnected with the are widely used to [illegible] of Ed[illegible] three wire lig[illegible] also installed for [illegible] with the use of 250 service or 125 [illegible] 250 volt service. Although the b[illegible] factured for [illegible] voltage, the General E[illegible] mends the three wire [illegible] as it is simpler. The motors may and the reserve margin of the motor is more conservative for tha[illegible] [illegible]



FIGS. 2,074 and 2,075.—General Electric charging sets. Fig. 2,074 set consists of dynamo and direct current motor; fig. 2,075 set consists of a dynamo and alternating current motor. Fig. 2,074 set is equipped with 125 volt, shunt wound dynamo and 230 or 550 volt motor and range in capacity from .125 kw. to 13 kw., the speed varying from 2,250 R.P.M. in the .125 kw. set to 925 R.P.M. in the 13 kw. set with 230 volt motor. Both motor and dynamo have the same type and size of frame; these are bolted together and form a compact and symmetrical outfit, no base being necessary. Sets of the type shown in fig. 2,075 range in capacity from .2 kw. to 10 kw. and are equipped with 125 volt shunt wound dynamo and 110, 220, 440 or 550 volt two or three phase motors. If desired they can be furnished with single phase motors wound for 110 or 220 volts. The speed of this type is 1,800 R.P.M. When a motor generator set is used to charge only one battery, the insertion of a resistance between the charging dynamo and the battery is not necessary, inasmuch as all adjustments of voltage can be made by varying the field strength of the dynamo, and, therefore, there are no large losses due to resistance since the loss in the dynamo field rheostat is very small. When a motor generator set is used to charge two or more batteries of different capacities, or voltages, or which are in different conditions of charge, it is necessary to insert a resistance in series with each battery, in order that the current may be properly adjusted for each particular battery.

Thus if the motor have six poles and the frequency be 50, the rotary field revolves at $50 \times 60 \div 3 = 1,000$ R.P.M., and the motor will revolve at one-half that speed or $1,000 \div 2 = 500$ R.P.M.

Since the connections are so arranged that these currents tend to set up in the armature a revolving field, rotating at half speed in a sense opposite to that in which the shaft is rotating at half speed, it follows that by the superposition of this revolving field upon the revolutions of the machine, the magnetic effect is equivalent to a rotation of the armature at whole speed so that it operates in synchronism, as does the armature of a rotary converter.

Half the electric input into the motor part is, therefore, turned into mechanical energy to drive the shaft, the other half acts inductively on the armature winding, generating currents therein.

As to the dynamo part it is half generator, receiving mechanical power by transmission along the shaft to furnish half its output, and it is half converter, turning the currents received from the armature into direct current delivered at the brushes.

Ques. What action takes place in the motor armature winding?

Ans. Since it runs at one-half synchronous speed, it generates alternating current of half the supply current frequency, delivering these to the armature of the dynamo.

Ques. What claim is made for this type of apparatus?

Ans. The cost is said to be less than a motor generator set, and it is claimed to be self-synchronizing and to require no special starting gear, also to be 2.5 per cent. more efficient than a motor generator.

Ques. How is the machine started from the high pressure side?

Ans. The field winding is connected directly to the high pressure leads. The three slip ring brushes are connected with external resistances which are used while starting, the external resistances being gradually cut out of the circuit as the machine comes up to speed (the same as with an ordinary slip ring motor).

Ques. How does a cascade converter compare with a synchronous converter?

Ans. It is about equally expensive as the synchronous converter with its necessary bank of transformers, but is about one per cent. less efficient. It is claimed to be more desirable for frequencies above 40 on account of the improved commutation at the low frequency used in the dynamo member. For lower frequencies the synchronous converter is preferable.

CHAPTER LIV

RECTIFIERS

The purpose of a rectifier is to change alternating current into a uni-directional or pulsating current. There are several classes of apparatus to which the term rectifier may be applied, as

1. Mechanical rectifiers;
2. Electrolytic rectifiers;
3. Mercury vapor rectifiers, or, mercury arc rectifiers;
4. Electro-magnetic rectifiers.

Mechanical Rectifiers.—By definition, a mechanical rectifier is a form of commutator operating in synchronism with the generator and commutating or rectifying the negative waves of the alternating current as shown graphically in figs. 2,076 and 2,078. The essential features of construction are shown in fig. 2,079.

Ques. Mention some application of a mechanical rectifier.

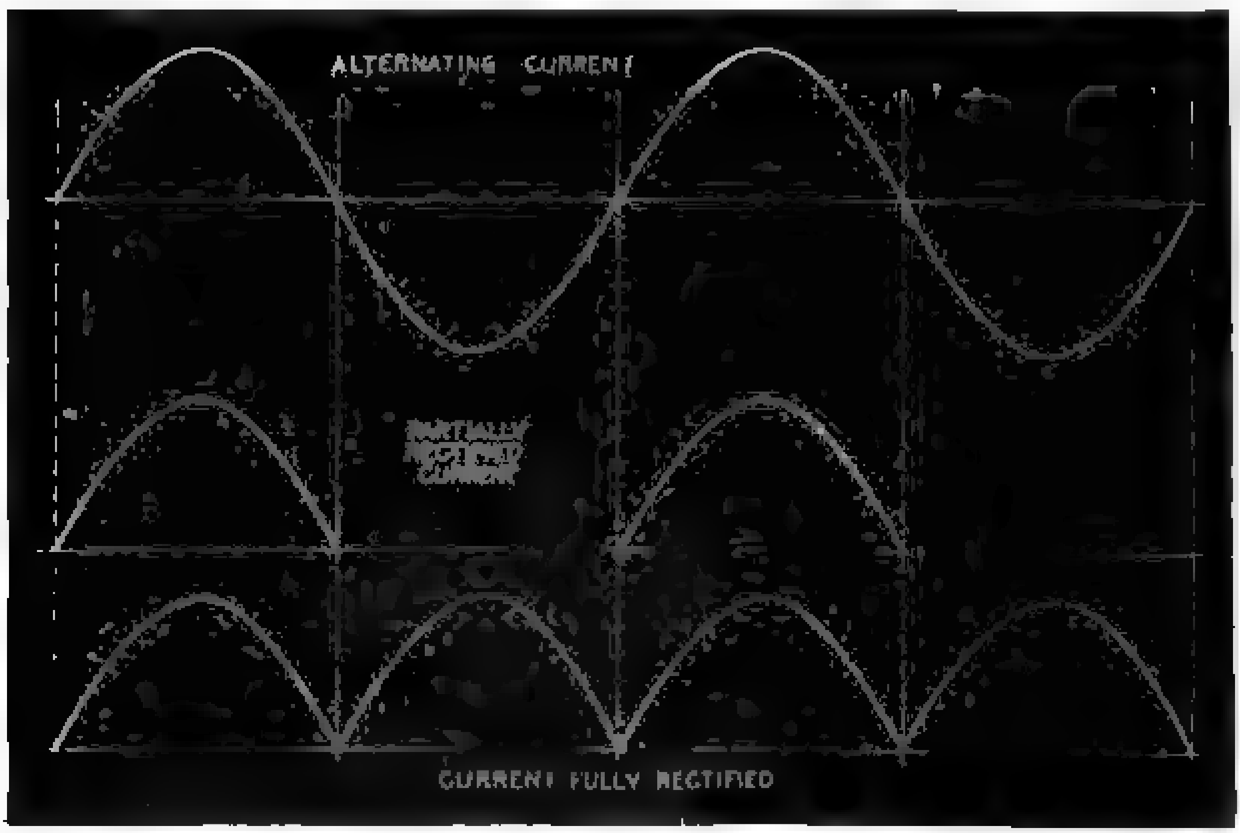
Ans. It is used on a compositely excited alternator as illustrated on page 1,192.

Electrolytic Rectifiers.—If two metals be placed in an electrolyte and then subjected to a definite difference of pressure, *they will* (under certain conditions) offer greater resistance to the

passage of a current in one direction, than in the other direction. On account of this so called valve effect, electrolytic rectifiers are sometimes called "valves."

Ques. What metal is generally used for the cathode?

Ans. Aluminum.



FIGS. 2,076 to 2,078.—Diagrams showing alternating currents, and partial and complete rectification.

Ques. What is generally used for the other electrode?

Ans. Lead or polished steel.

Metals of low atomic weight exhibit the valve effect at high differences of pressure, and heavier metals at low differences of pressure.

Ques. Describe the "Nodon valve."

Ans. The cathode is of aluminum or aluminum alloy, and the

other electrode, which has considerably more surface, is the containing vessel. The electrolyte is a neutral solution of ammonia phosphate.

Ques. Describe its action.

Ans. It is due to the formation of a **film** of normal hydroxide of aluminum, over the surface of the aluminum electrode. This

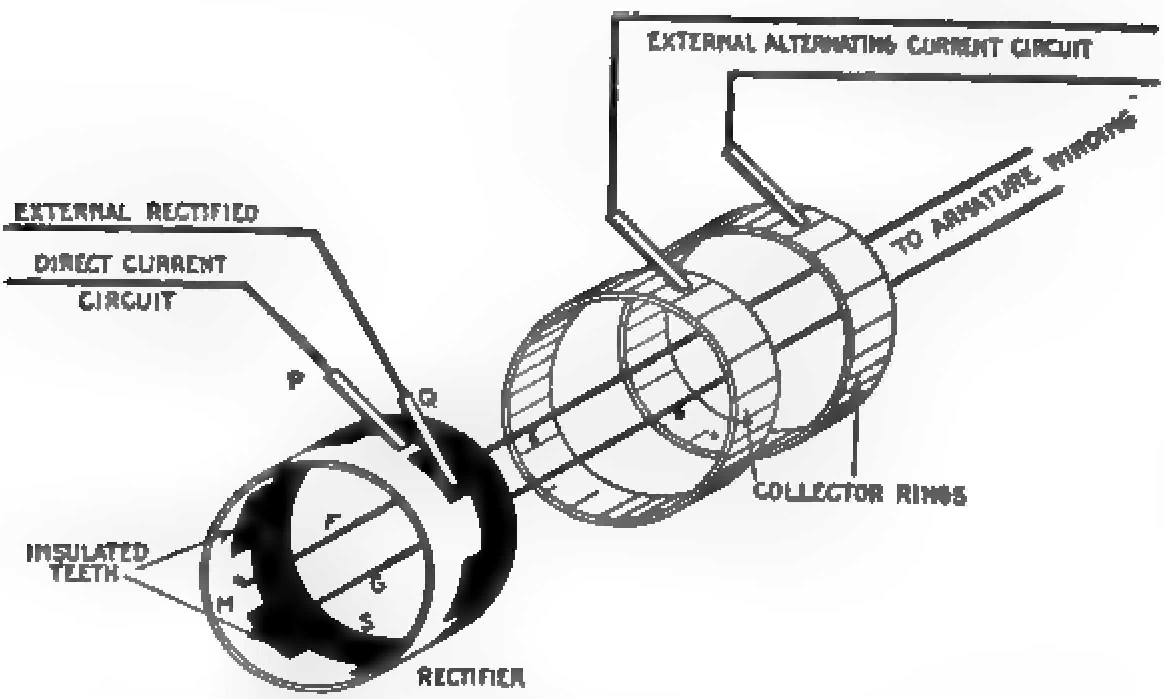
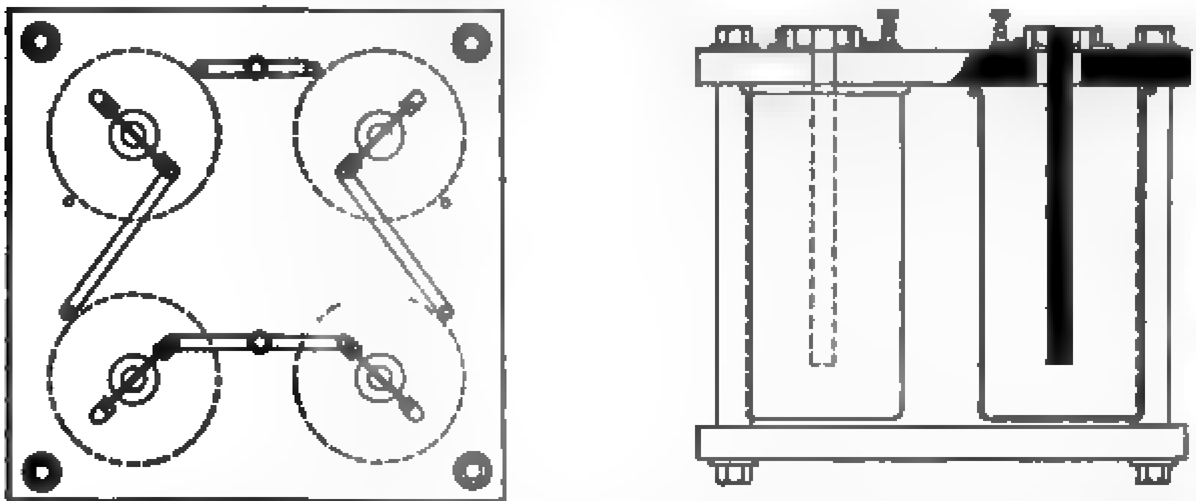


FIG. 2,079.—Mechanical rectifier. The rectifier consists of two castings M and S with teeth which fit together as shown, being insulated so they do not come in contact with each other. Every alternate tooth, being of the same casting, is connected together, the same as though joined by a conducting wire. There are as many teeth as there are poles. The part M of the rectifier is connected to one of the collector rings by F, and the part S to the other ring by G.

film presents a very high resistance to the current when flowing in one direction but very little resistance, when flowing in the reverse direction.

Ques. What is the effect when a Nodon cell is supplied with alternating current?

Ans. Half of the wave will be suppressed and an intermittently pulsating current will result as shown in fig. 2,077.



FIGS. 2,080 and 2,081.—Two views of Nodon valve. This is an electrolytic rectifier in which the cathode is a rod of aluminum alloy held centrally in a leaden vessel which forms the anode and contains the electrolyte, a concentrated solution of ammonium phosphate. Only a short portion at the lower end of the cathode is utilized, the rest, which is rather smaller in diameter, being protected from action by an enclosing glass sleeve. The current density at the cathode ranges from 5 to 10 amp. per sq. dm. In the larger sizes, the cells are made double, and a current of air is kept circulating between the walls by means of a motor driven fan. In order to utilize both halves of the supply wave, the Gratz method of connection is adopted. The maximum efficiency is obtained at about 140 volts, and the efficiency lies between 65 and 75 per cent., and is practically independent of the frequency between the limits of 25 ~ and 200 ~. Above a pressure of 140 volts, the efficiency falls off very rapidly, owing to breakdown of the film. The pressure difference is high, being over 90 per cent. at full load. Temperature largely influences the action of the valve, and should never exceed 122° Fahr.

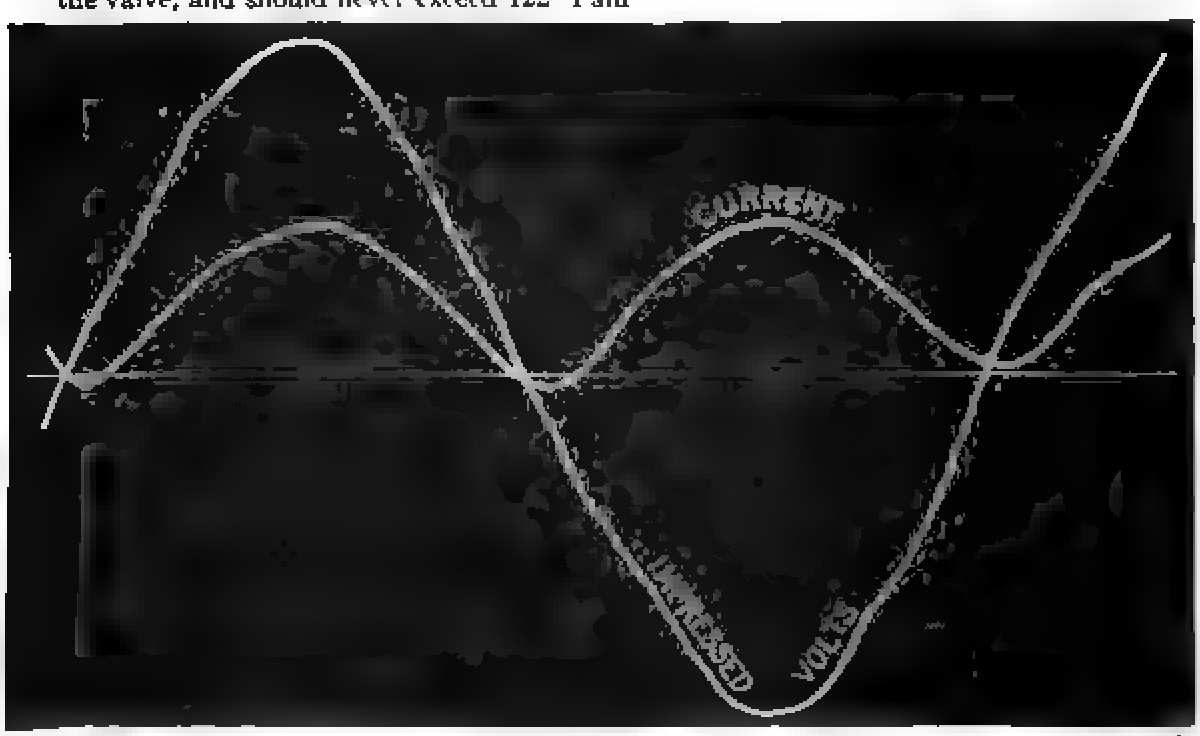


FIG. 2,082.—Oscillograph record from Nodon valve showing original supply voltage and the corresponding pulsating current at the terminals of such a valve.

Ques. How may both halves of the alternating waves be utilized?

Ans. By coupling a series of cells in opposed pairs as in fig. 2,080.

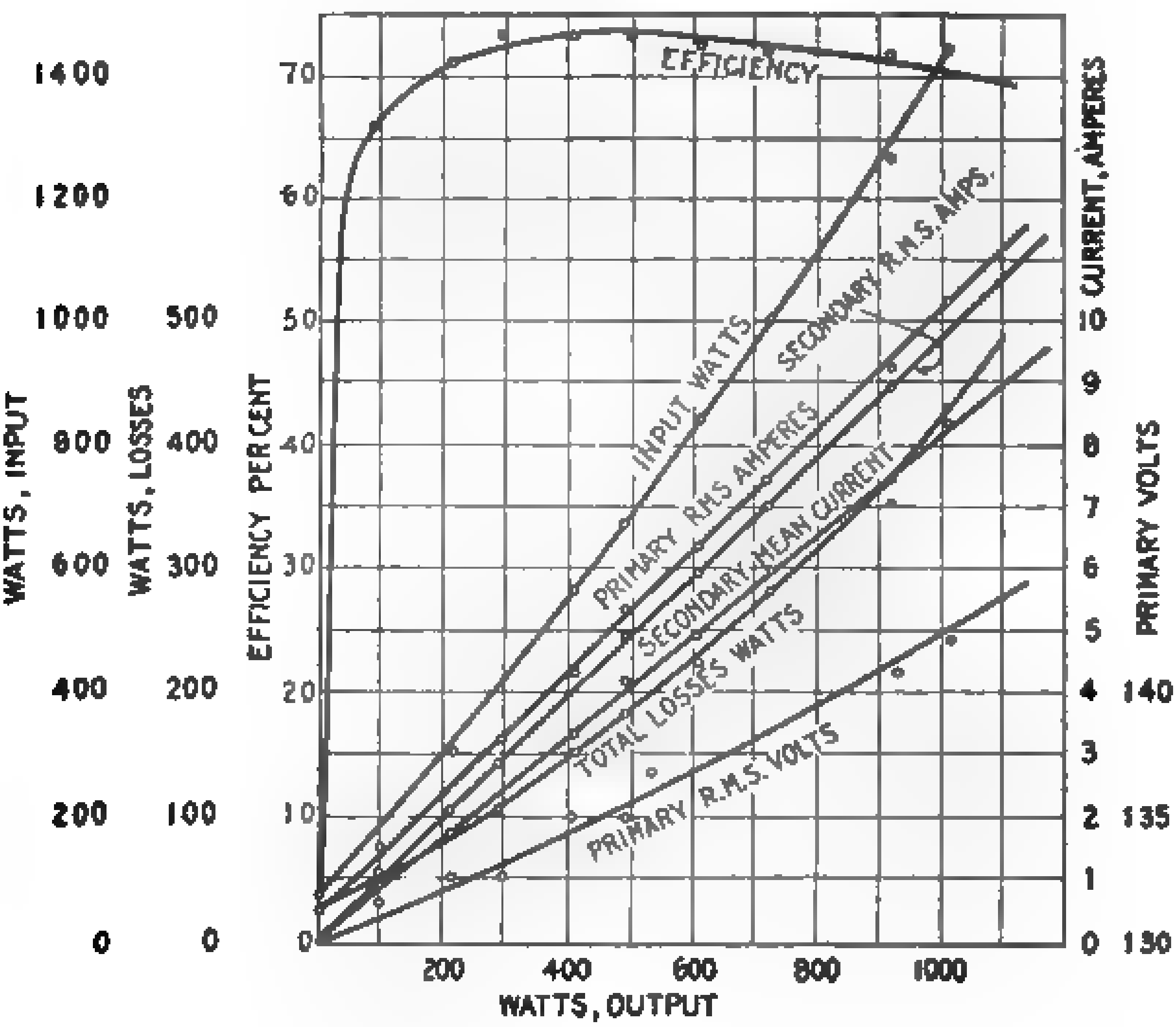


FIG. 2,083.—Performance curves of five ampere Nodan valve. Constant secondary voltage test. Loaded on non-inductive resistances. Frequency 60. Maximum power factor on valve .7.

Ques. Upon what does the efficiency of the film depend?

Ans. Upon the temperature.

It should not for maximum efficiency exceed 86 degrees Fahr. There is also a certain critical voltage above which the film breaks down locally, giving rise to a luminous and somewhat disruptive discharge accompanied by a rapid rise of temperature and fall in efficiency.

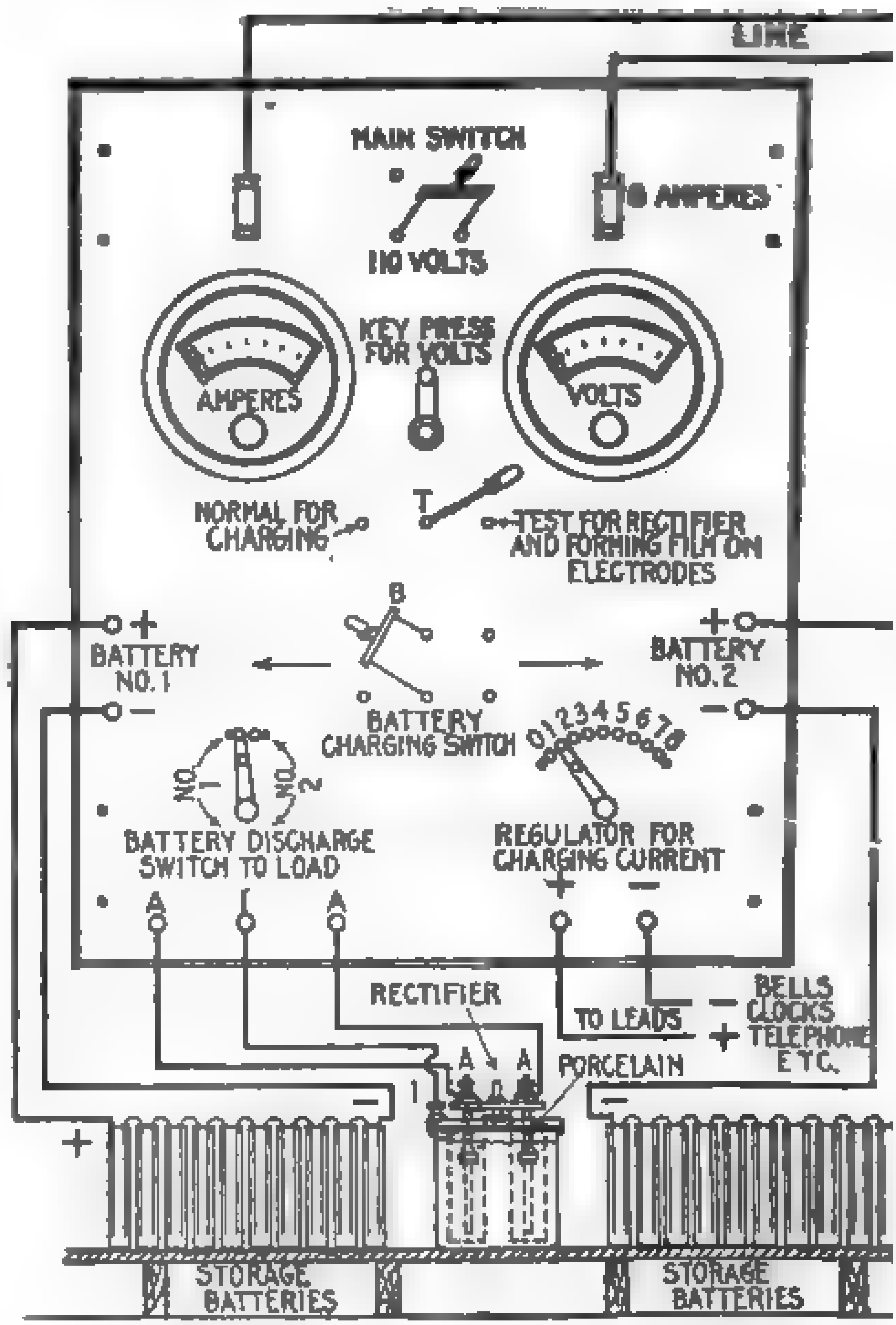
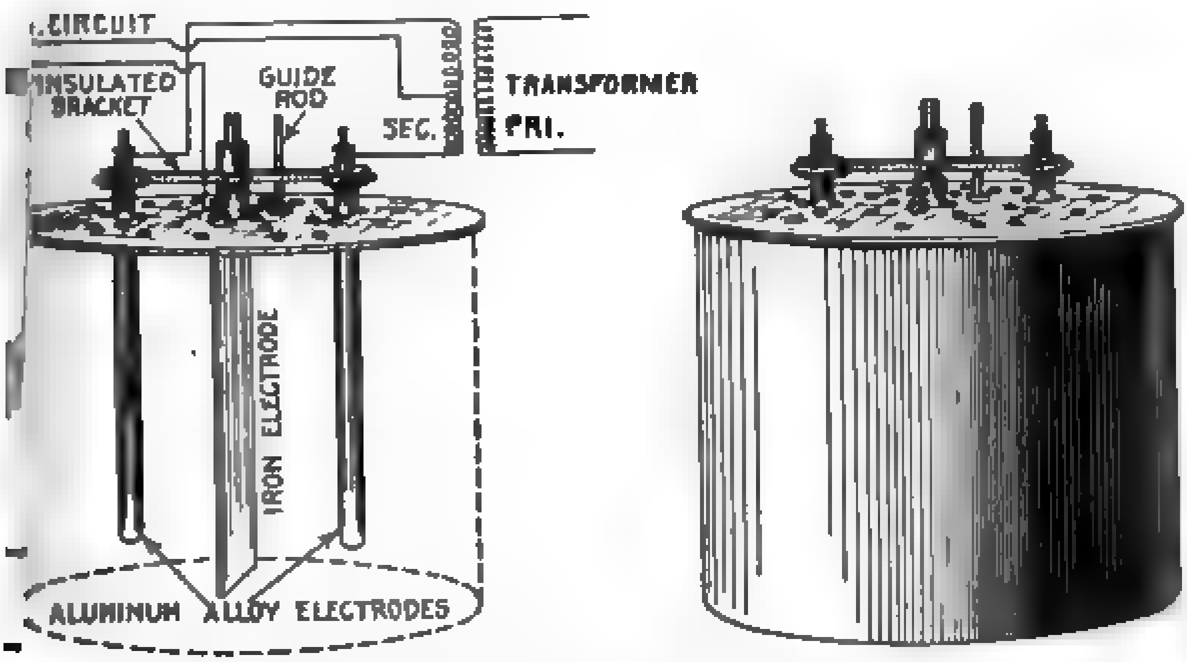


FIG. 2,084.—Mohawk electrolytic rectifier and switchboard; diagram showing for charging storage battery. Operating instructions: After assembling b fig. 2,085, the film must be formed on the aluminum alloy electrodes so that will pass current only in the right direction. Open switch B, close switch T discharge lever can be in any position; charging regulator lever must be to left, the zero position; now close main switch M. Moving regulator lever R f position to the first button or contact, let it remain there for a time, not less tha

Ques. When an electrolytic rectifier is not in use for some time what happens?

Ans. The electrodes will loose the film.



FIGS. 2,085 and 2,086.—Mohawk electrolytic rectifier. To put in commission, clean out the jar. Fill with distilled or rain water. Add six pounds of electro salts, stir and after all salts are dissolved place the cover in position. The specific gravity of the solution should be 1.125. The middle iron electrode must hang straight down in the solution and not touch either of the other aluminum alloy electrodes. The aluminum alloy electrodes are mounted on an insulated bracket that slides up and down on a ¼″ rod. This rod screws in the hole taped in the middle of the cover. The electrodes give the best results only when perfectly smooth. Should they get rough, covered with a deposit or a white coating remove from the solution, and clean with fine sand paper. Finish with fine sand paper. Form the film again and the electrodes will be as good as new. Clean iron electrode occasionally.

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utes; *this is important*, as the proper rectification of the current depends on the film formed on the aluminum rods. The ammeter after the first rush of current may not show any current as passing, or it may show a reverse current. In the latter case, leave the contact finger on the first button until the needle comes back to zero. This may take some time, but the needle will eventually come back, it also indicates that the film is properly formed when the needle returns to zero. Move regulator R to the extreme right step by step and note that the ammeter continues to return to zero, which indicates that the film on rectifier electrodes is formed properly. Move regulator R to zero, close switch T to the left in normal charging position. Close charging switch B. To regulate the flow of current through the battery move charging lever R to the right slowly until ammeter indicates the correct charging current. After the batteries are charged and ready for use, discharge lever can be moved to connect either set of storage batteries to the load terminal. The voltage of the batteries can be read at any time, by pressing the strap key. The discharge lever connects the batteries to the volt meter and it is possible by moving it to measure the voltage of either set of battery, charging or discharging. Trouble in the rectifier demonstrates itself by the solution becoming heated. The condition of the rectifier can be tested any time in a few seconds by opening switch B and closing switch T to the right. If the rectifier be in proper condition the ammeter will read zero. And if it be not rectifying and permitting A.C. current to flow through the rectifier, the ammeter will read negative or to the left of the zero. An old solution that is heating and not rectifying properly will turn a reddish brown [illegible]

Ques. What must be done in such case?

Ans. The electrodes must be reformed.

Ques. How is the loss of film prevented?

Ans. By removing the electrodes from the electrolyte and drying them.

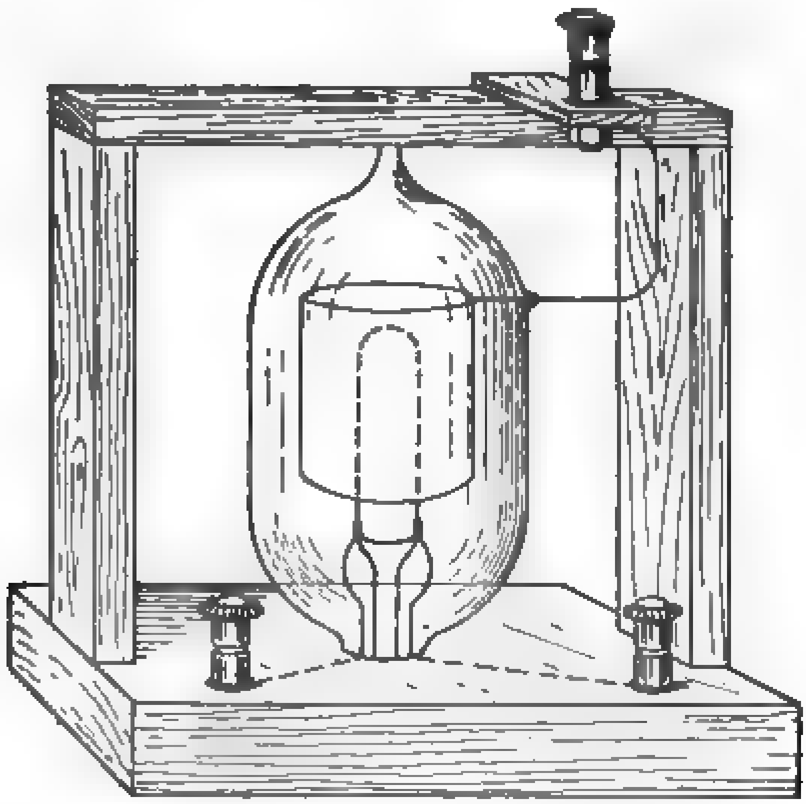


FIG. 2,087.—The Fleming oscillation valve. It depends for its action on the well-known Edison effect in glow lamps. The valve consists of a carbon filament glow lamp with a simple central horseshoe filament. Around this filament inside the exhausted bulb is fixed a small cylinder of nickel, which is connected by means of a platinum wire sealed through the bulb to a third terminal **The valve is used as follows:** *The carbon loop is made incandescent by a suitable battery. The circuits in which the oscillations are to be detected is joined in series with a sensitive mirror galvanometer, the nickel cylinder terminal and the negative terminal of the filament of the valve being used.* The galvanometer will then be traversed by a series of rapid discharges all in the same direction, those in the opposite direction being entirely suppressed.

Ques. What attention must be given to the electrolyte?

Ans. Water must be added from time to time to make up for evaporation.

This is necessary to keep the solution at the proper density.

Ques. What is the indication that the rectifier needs recharging?

Ans. Excessive heating of the solution with normal load.

Ques. What is the indication that a rectifier is passing alternating current?

Ans. It will heat, and if the solution be very weak, it will cause a buzzing sound.

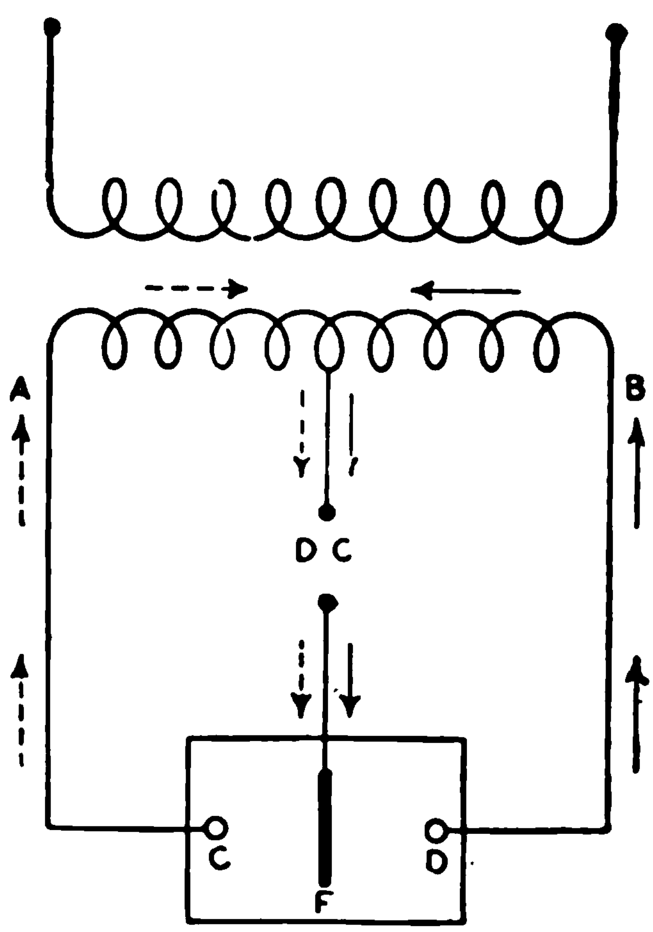


Fig. 2,088.—The Churcher valve. This is of the modified Nodon type. It differs from the latter in that it has two cathodes of aluminum and an anode of lead or platinum, suspended in the one cell. This permits the complete utilization of both halves of the supply wave with one cell instead of the four required in the Gratz method. The connections of such a cell are shown in the figure. The secondary of the transformer carries a central tapping, and is connected through the direct current load to the central anode, while each of the cathodes is connected to the ordinary terminals of the transformer itself. The practical limits of the cell are 50 volts direct current, or 130 volts at the transformer terminals AB. F, is the anode; C, cathode I; D, cathode II.

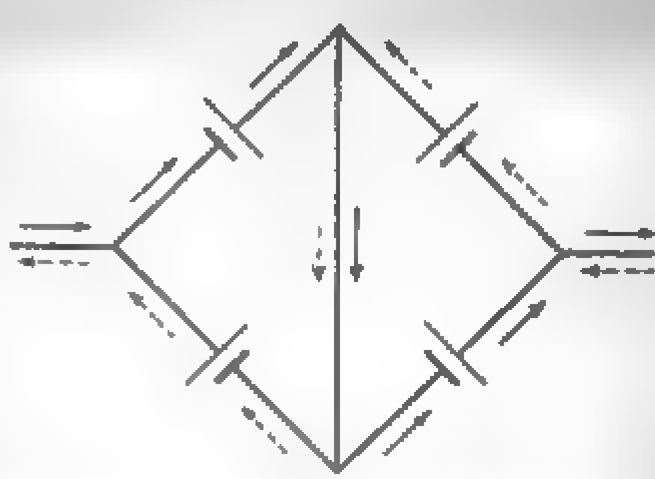
Ques. What harm is caused by operating a rectifier with a weak electrolyte?

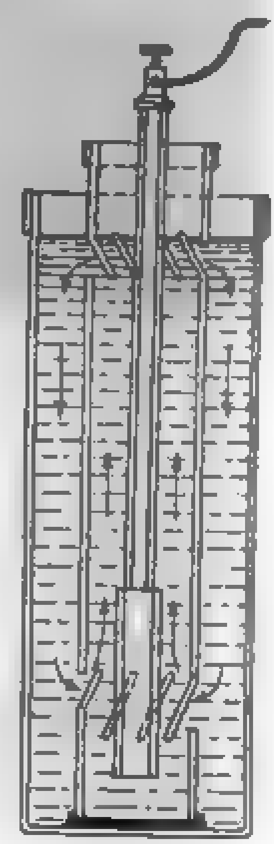
Ans. The electrodes will eat away.

A few of the so called electrolytic valves are here briefly described:

The Audion Valve.—This valve was invented by De For
and is practically identical with the Fleming oscillation
latter being illustrated in fig. 2,087.

Grisson Valve.—In this valve the cathode is a sheet of
and the anode, a sheet of lead, supported, in the original
zontally in a vessel containing the electrolyte, consisting of
of sodium carbonate. Cooling is effected by circulating wat
metal tubes in the electrolyte itself.

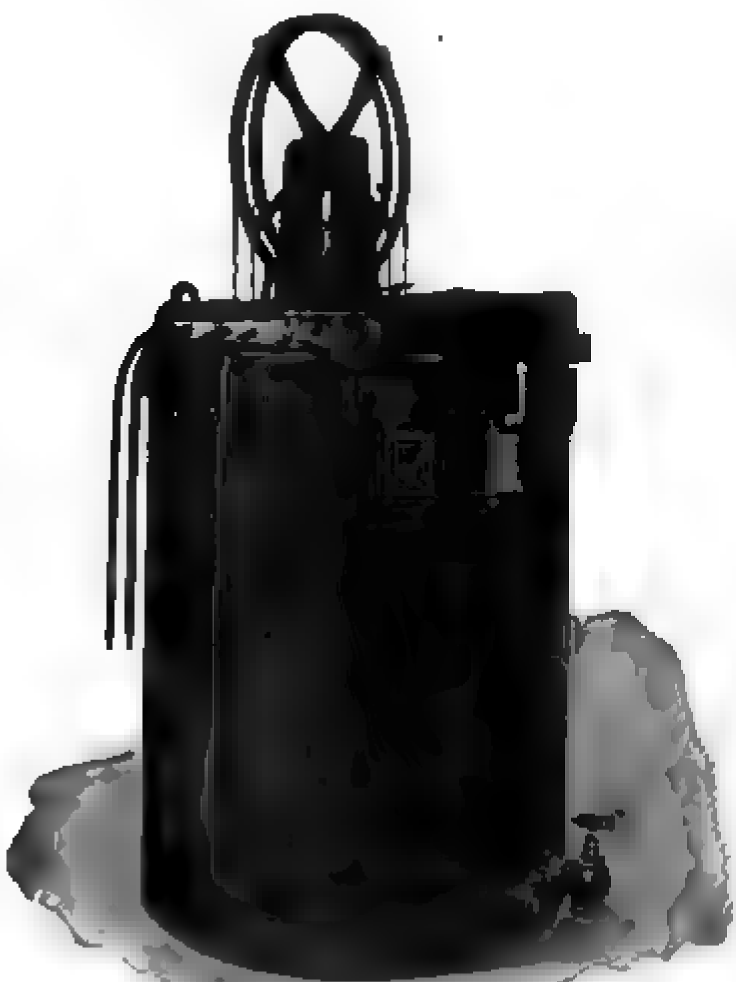




FIGS. 2,089 and 2,090. The De Faria valve. This is an aluminum lead rectifier.
is a hollow cylinder of aluminum placed concentrically in a larger cylinder
the whole immersed in electrolyte of sodium phosphate in an ebonite conta
Cooling is effected by promoting automatic circulation of the electrolyte by p
lead cylinder with holes near its extremities, the heated electrolyte then rise
cylinder, passes out at the upper holes, is cooled by contact with the walls
taining vessel and descends outside the lead cylinder. It is claimed that
action is sufficient to allow of a current density of 8 amp. per sq. dm. of alum

Pawlowski Valve.—This is an electrolytic valve employi
electrolyte. It consists of a copper plate which has been coa
crystalline layer of carefully prepared copper hemisulphide, pr
melting sulphur and copper together out of contact with air.
pared plate is placed in contact with an aluminum sheet and
bination is then *formed* by submitting it to an alternating
until sparking, which at first occurs, ceases.

Giles Electric Valve.—This consists of a combination of spark gaps and capacity used to protect electrical apparatus against damage due to atmospheric discharges and resonance surges. The spark gaps are formed between the edges of sharp rimmed discs of non-arcing metal. These discs are insulated from each other, and from the central tube, which provides a support for the apparatus and also an earth. The condenser effect is obtained by means of the annular discs and the tube; an adjustable spark gap, a high resistance, and a fuse all connected in series, complete the valve.



2,091.—75 light Westinghouse-Cooper Hewitt mercury vapor rectifier constant current regulating transformer. View showing assembly in case.

Buttner Valve.—It is of the Nodon type employing a cathode of magnesium-aluminum alloy, and probably iron or lead as anode, with an electrolyte of ammonium borate. Buttner claims that the borate is superior to the phosphate in that it does not attack iron, and will keep in good working condition for longer periods.

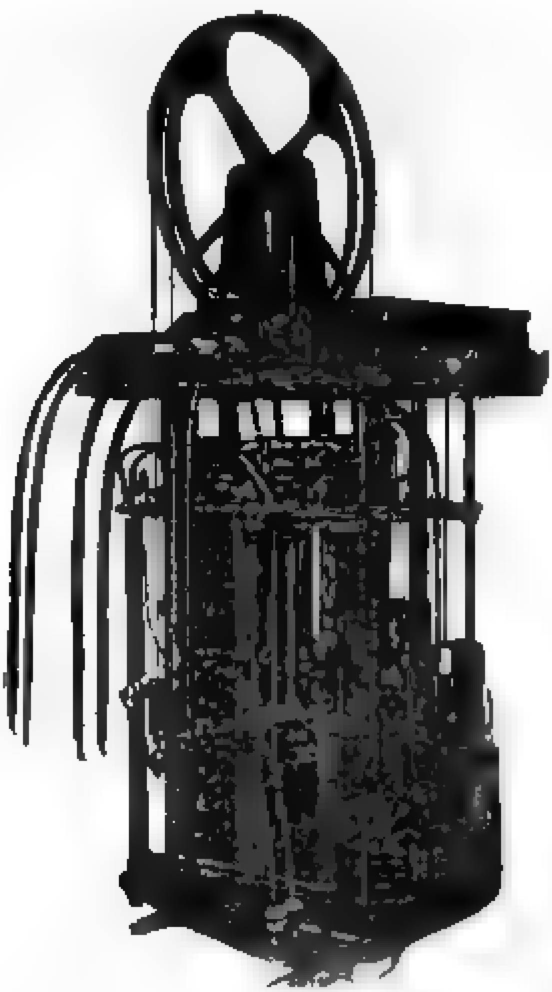


FIG. 2,092.—75 light Westinghouse-Cooper Hewitt mercury vapor rectifier constant current regulating transformer with case removed. The transformer is of the repulsion coil type, oil cooled and oil insulated. It is so arranged as to give a constant secondary current and to insulate the arc lines from the primary circuit. The regulating transformer contains two stationary secondary coils and two moving primary coils balanced against each other. Each secondary coil of the 75 light regulator is wound in two parts, owing to the use of two rectifier bulbs in series in outfits of this capacity. The repulsion between the primary and secondary coils changes the distance between them according to the variation of load, and the induced current in the secondary is thus kept constant. An increase in current causes the primary and secondary coils to separate, and a decrease in current permits them to approach each other, until the normal balance is restored. The moving coils are hung from sheave wheels having roller bearings and are balanced so that they are sensitive to the slightest impulse tending to separate them or draw them closer together. (See figs. 1,981-2, and 2,111.) The windings are insulated for a voltage considerably in excess of that existing in normal service. Several taps are provided to take care of different voltages and wave forms. A combination of taps will be found which will be suitable for any wave form coming within the American Institute of Electrical Engineer's limits for a sine wave. The secondary coils are also provided with taps for 85 per cent. of normal load, so that less than normal load can be taken care of at a good power factor. Any part of the full load can be carried temporarily with the full load connections of the transformer, but at permanent light loads the power factor and efficiency will be improved by using the 85 per cent. connections. Standard regulating transformers are wound for 6.6 and 4 amperes, and for primary circuits of 220, 440, 1,100 2,200, 6,600 and 13,200 volts. Regulators can be specially wound for 5.5 amperes. For *three phase* circuits three regulators can be used, one on each phase, or they can be furnished in pairs with an auxiliary auto-transformer to give a balanced load. The regulators can be connected, in cases where the unbalancing is not objectionable, to separate phases.

Mercury Vapor Rectifiers.—The Cooper Hewitt mercury vapor rectifier, as shown in fig. 2,093 consists essentially of a *hermetically sealed glass bulb filled with mercury vapor and provided with four electrodes.* The two upper electrodes are of solid material and the two lower of mercury.

The solid electrodes are the positive electrodes; the mercury electrodes are the negative electrodes.

The mercury pools of the two lower electrodes are not in contact when the bulb is vertical, but the bulb is so mounted

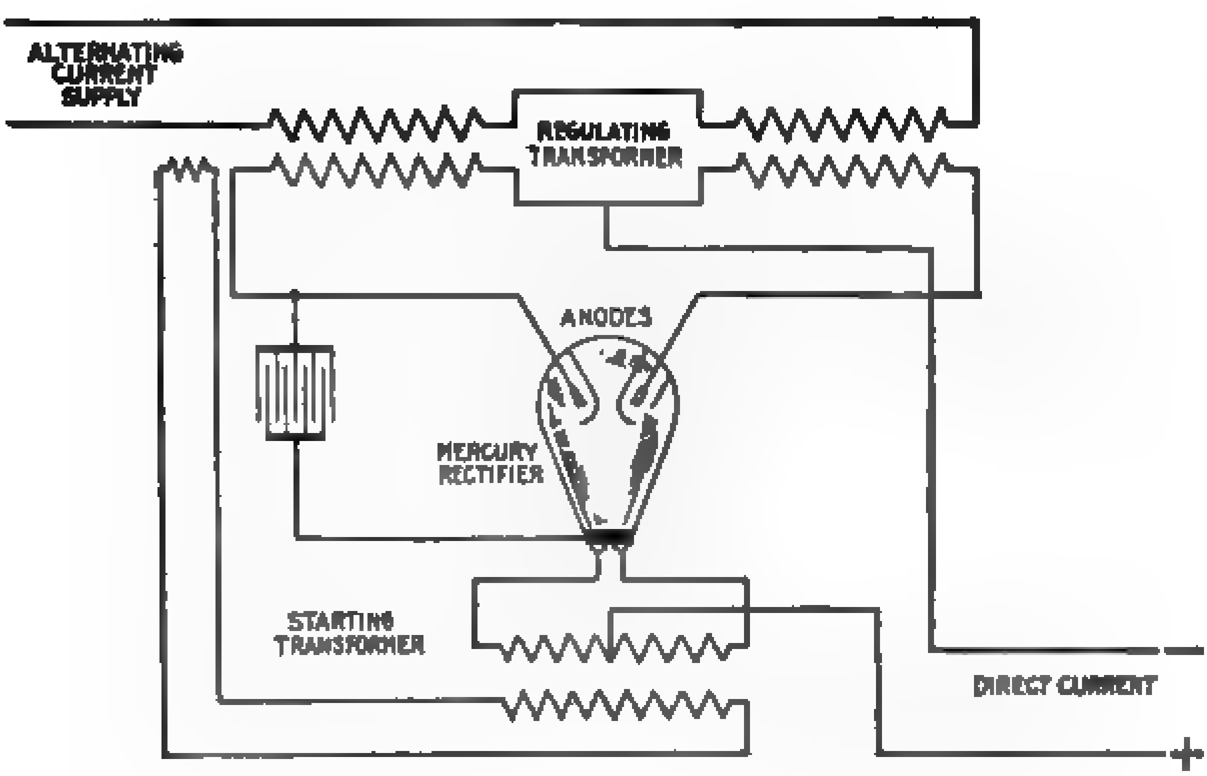


FIG. 2,093.—Diagram of connections of Westinghouse-Cooper Hewitt mercury vapor rectifier arc light circuit.

that it can be tilted to bring these two pools temporarily in contact for starting.

The bulb contains highly attenuated vapor of mercury, which, like other metal vapors, is an electrical conductor under some conditions. The positve electrodes are surrounded by this

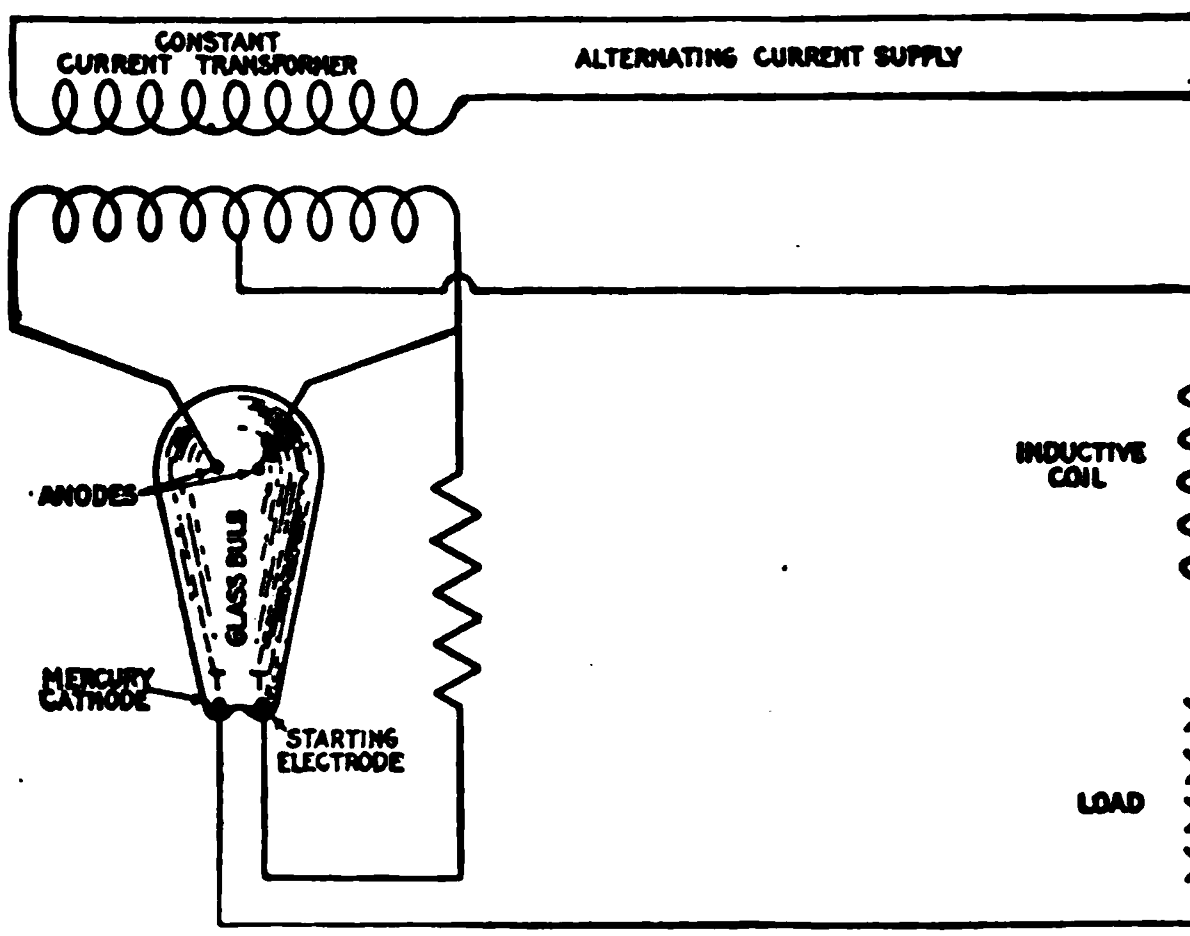


FIG. 2,094.—Cooper Hewitt mercury vapor rectifier. The mercury vapor rectifier as developed by Peter Cooper Hewitt for changing alternating current into direct current is the result of a series of careful experiments and investigations of the action going on in his mercury vapor lamp for electric lighting used on direct current circuits only. While many attempts have been made to produce an alternating current lamp, up to the present time, they have been unsuccessful. The difficulty of operating a lamp on the alternating current circuit lies in the fact that while a current will flow freely through it in one direction, when the current reverses the negative electrode or cathode acts as an electric valve and stops the current, thus breaking the circuit and putting out the light. By following up this new electrical action, Hewitt applied the principle in the construction of a vacuum tube with suitable electrodes, and by using two electrodes of iron or graphite for the positive or incoming current and one of mercury for the negative or where the current leaves the tube, the circuits could be arranged so that a direct current would flow from the mercury electrode and be used for charging storage batteries, electro-chemical work or operating direct current flame arc lamps. As shown in the figure, **the rectifier consists essentially** *of a glass bulb into which are sealed two iron or graphite anodes and one mercury cathode, and a small starting electrode.* The bulb is filled with mercury vapor under low pressure. The action of this device depends on *the property of ionized mercury vapor of conducting electricity in one direction only.* **In operation** no current will flow until the starting or negative electrode resistance has been overcome by the ionization of the vapor in its neighborhood. To accomplish this, the voltage is raised sufficiently to cause the current to jump the gap between the mercury cathode and the starting cathode, or by bringing the cathode and starting electrode together in the vapor by tilting and then separating them, thus drawing out the arc. When this has been done, current will only flow from the anode to the mercury cathode, and not in the reverse direction. In order to maintain the action, a lag is produced in each half wave by the use of a reactive or sustaining coil; hence the current never reaches its zero value, otherwise the arc would have to be restarted. **There are two kinds of losses in the tube:** 1, *arcing, or leakage from one anode to the other*, and 2, *the mercury arc voltage drop.* This drop does not depend on the load, the energy represented by the drop being converted into heat, which is dissipated at the surface of the containing vessel. According to Steinmetz, the limit of voltage must be very high, as 36,000 volts has been rectified. The current output is limited principally by the leading-in wires to the electrodes, it being a difficult problem to seal into the glass container the large masses of metal required for the conduction of large currents. Frequency has but little influence. The direct current voltage ranges from 20 to 50 per cent. that of the arc supply. The life of the valve depends somewhat upon its size, being longer in the small sizes and never, with fair usage, less than 1,000 hours.

[redacted]

vapor. Current can readily pass from either of the solid electrodes to the mercury vapor and from it to the mercury electrode, but when the direction of flow tends to reverse, so that current would pass from the vapor to the solid electrode, there is a resistance at the surface of the electrode, which entirely prevents the flow of current.

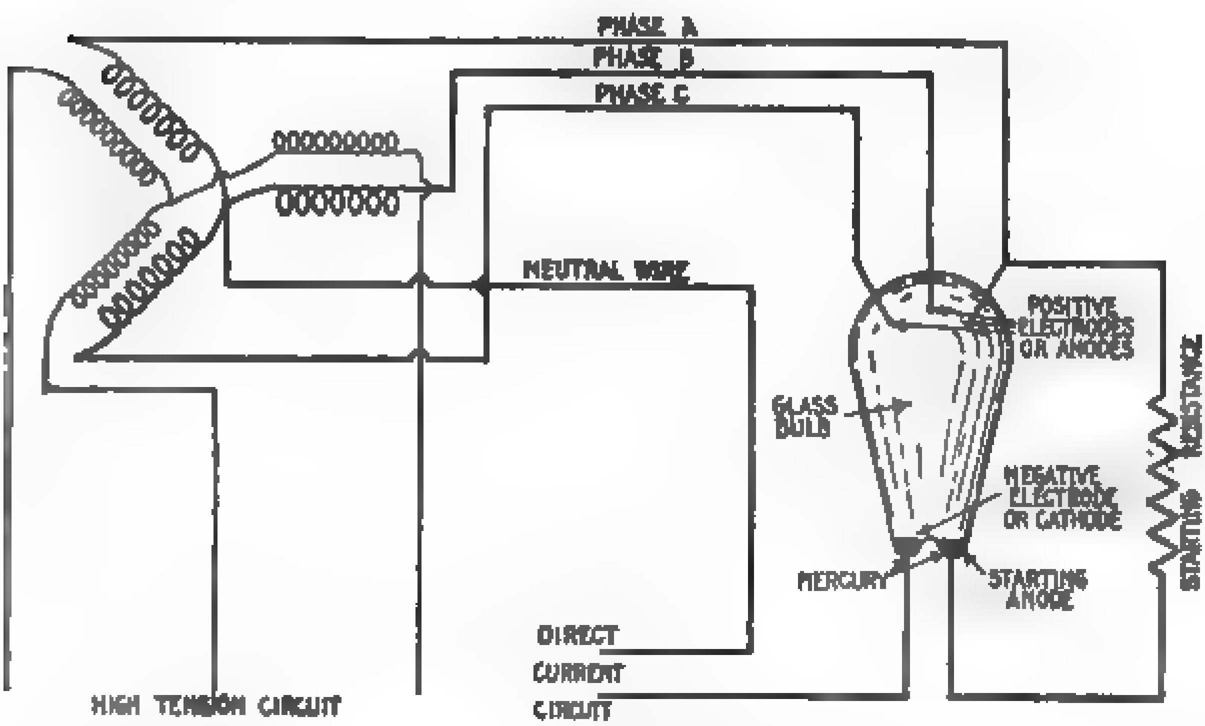
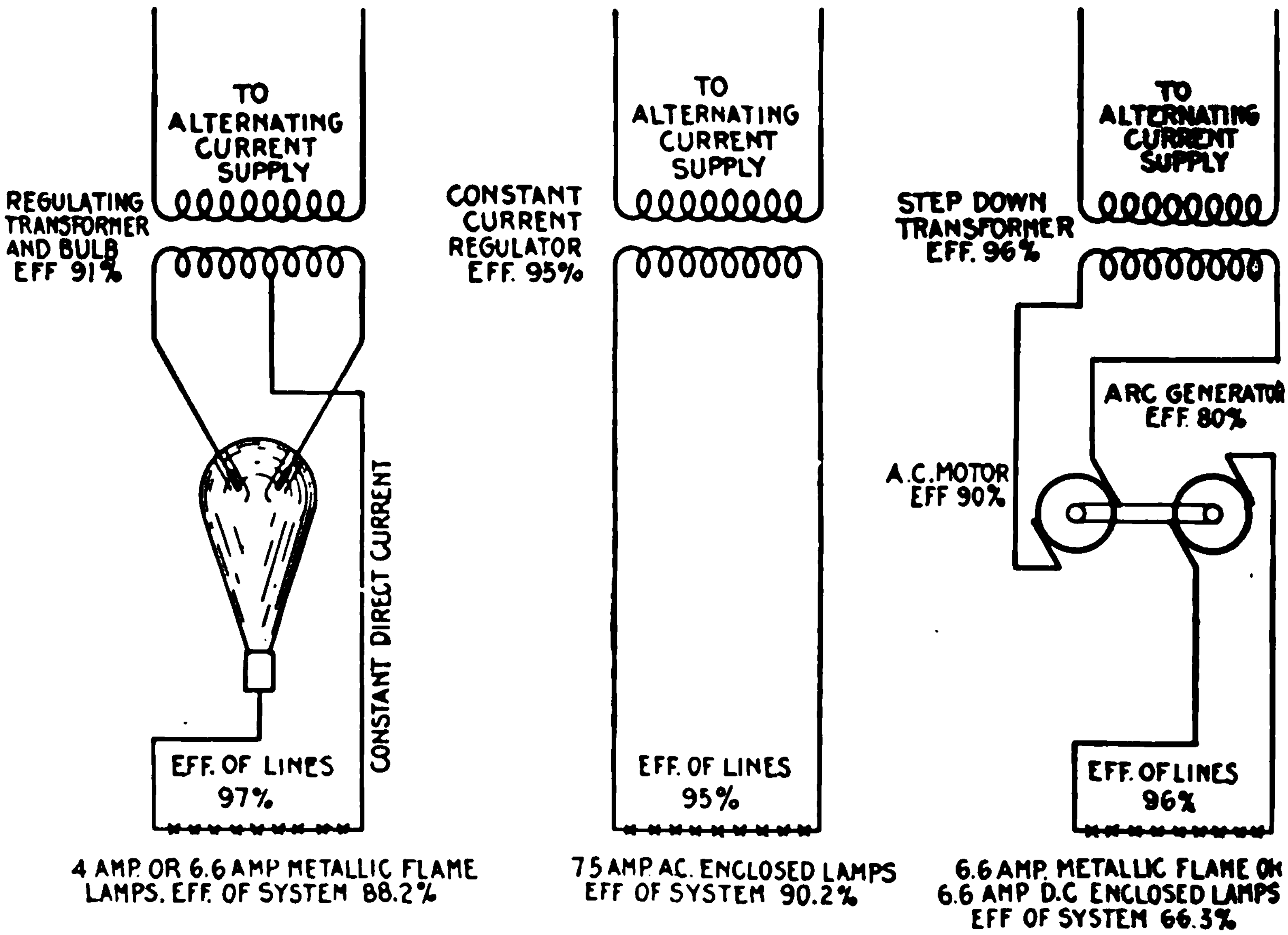


FIG. 2,095.—Three phase mercury arc rectifier. The rectifier bulb is provided with three positive electrodes or anodes, a negative electrode or cathode, and a starting anode, as shown. The three phase leads are connected to the anodes at the top of the bulb, a branch from one phase being brought down to the starting anode, a resistance being placed in the circuit to prevent excessive current on account of the proximity of the two lower electrodes. Since there is always a pressure on one of the three anodes in the right direction, a reactance coil is not necessary. The apparatus is started in the usual way by tilting.

The alternating current supply circuit is connected to the two positive electrodes as shown in the diagram, and as the electrodes will allow current to flow in only one direction and oppose any current flow in the opposite direction, the pulsations of the current pass alternately from one or the other of the positive *electrodes into* the mercury.

As these currents cannot pass from the vapor into either positive electrode, they are constrained to pass out all in one direction through the mercury electrode, from which they emerge as a uni-directional current. The positive electrodes of the rectifier thus act as check valves, permitting current to



FIGS. 2,096 to 2,098.—Westinghouse diagrams showing comparative efficiencies of different systems of series arc lighting.

pass into the mercury vapor but not allowing it to pass from the vapor to the solid electrodes.

Ques. What condition prevails before the bulb starts to rectify?

Ans. There appears to be a high resistance at the surface

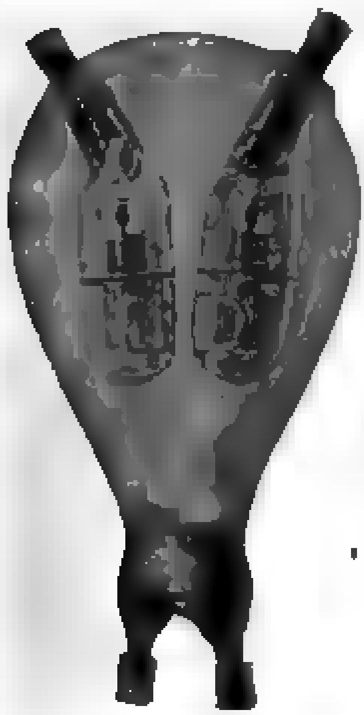


FIG. 2,099.—Westinghouse Cooper Hewitt mercury vapor rectifier bulb. It consists essentially of a hermetically sealed glass bulb filled with highly attenuated vapor of mercury, and provided with electrodes. Its operation is fully explained in the accompanying text.

FIG. 2,100.—Westinghouse-Cooper Hewitt mercury vapor rectifier bulb and box. The life of the bulb is materially increased by operating it at certain temperatures and for this reason the bulbs in the arc light rectifier outfits are immersed in oil and mounted in the same tank with the regulating transformer. Two bulbs in series are used with the 75 light outfit. The bulb is mounted on tilting trunions in a box which can be lifted out through a door in the top of the tank without disconnecting any leads. The containing box has contacts on the bottom so arranged that when it is lowered into place, the bulb is automatically connected in circuit. To replace a defective bulb it is only necessary to lift out the containing box by its handle through the door in the top of the case and mount a new bulb in it, after which the box can be lowered into place. It is desirable to have at each installation, a spare bulb box in which a bulb can be kept, connected ready for use. If this be done, it is only necessary, in case of trouble with the bulb, to withdraw the old bulb and box and replace them with the spare set. This avoids having the lamps out of service.

[redacted]

of the mercury, which must be broken down so that the current can pass.

Ques. What is this apparent surface resistance called?

Ans. *The negative electrode resistance.*

Ques. What must be done before any current can pass?

Ans. The negative electrode resistance must be overcome.

When once started the current will continue to flow, meeting with practically no resistance as long as the current is uninterrupted.

Ques. What will happen if the current be interrupted even for the smallest instant of time?

Ans. The negative electrode resistance will re-establish itself, and stop the operation of the bulb.

Ques. How is the negative electrode resistance overcome?

Ans. The bulb is tilted or shaken so that the space between the mercury electrodes is bridged by the mercury.

Ques. What happens when the bulb is tilted?

Ans. Current then passes between the two mercury electrodes from the starting transformer and the little stream of mercury which bridges the space between the electrodes breaks with a spark as the bulb is returned to its vertical position.

Ques. What duty is performed by the spark?

Ans. It breaks down the negative electrode resistance.

Ques. What conditions are now necessary for continuous operation of the rectifier?

Ans. The rectifier will now operate indefinitely as long as the current supply is uninterrupted and the direct current load *does not fall* below the minimum required for the arc.

[redacted]

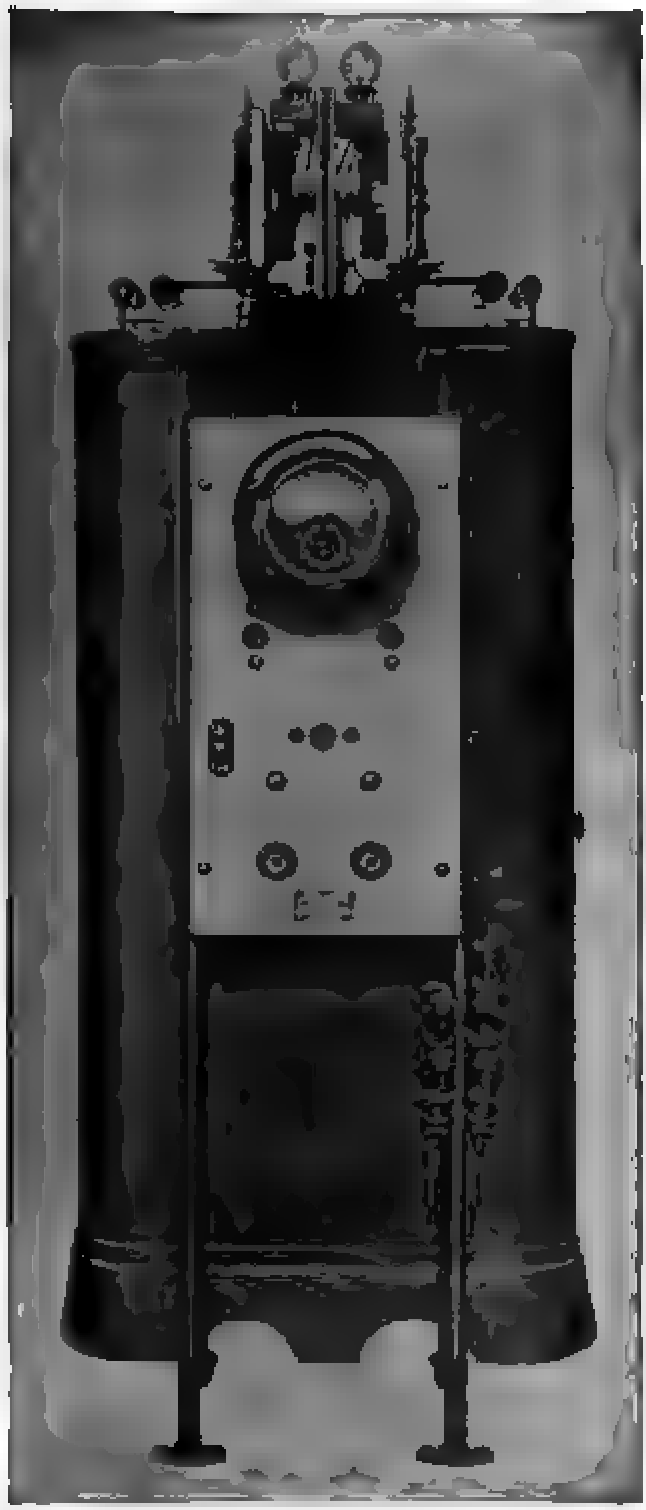


FIG. 2,101.—General Electric 50 light double tube combined unit series mercury arc rectifier outfit; front view. This unit consists of a constant current transformer, reactance, tube tank and exciting transformer mounted on a common base; also a static discharger and pilot lamp mounted on top of the transformer. This arrangement makes the rectifier outfit, with the exception of the switchboard panel, complete in itself.

Ques. Is the rectifier self-starting?

Ans. After the bulb has been started a few times, as described above, it becomes self-starting, so that under all ordinary operating conditions it will commence to operate when the switches connecting it with the load and the alternating current supply are closed.

Ques. What provision is made in the Westinghouse-Cooper Hewitt rectifier to render it self-starting?

Ans. It is rendered self-starting by means of a condenser.

Ques. Describe the arrangement and operation of the condenser.

Ans. The condenser is connected between one of the positive electrodes and a coating of tinfoil outside

[redacted]

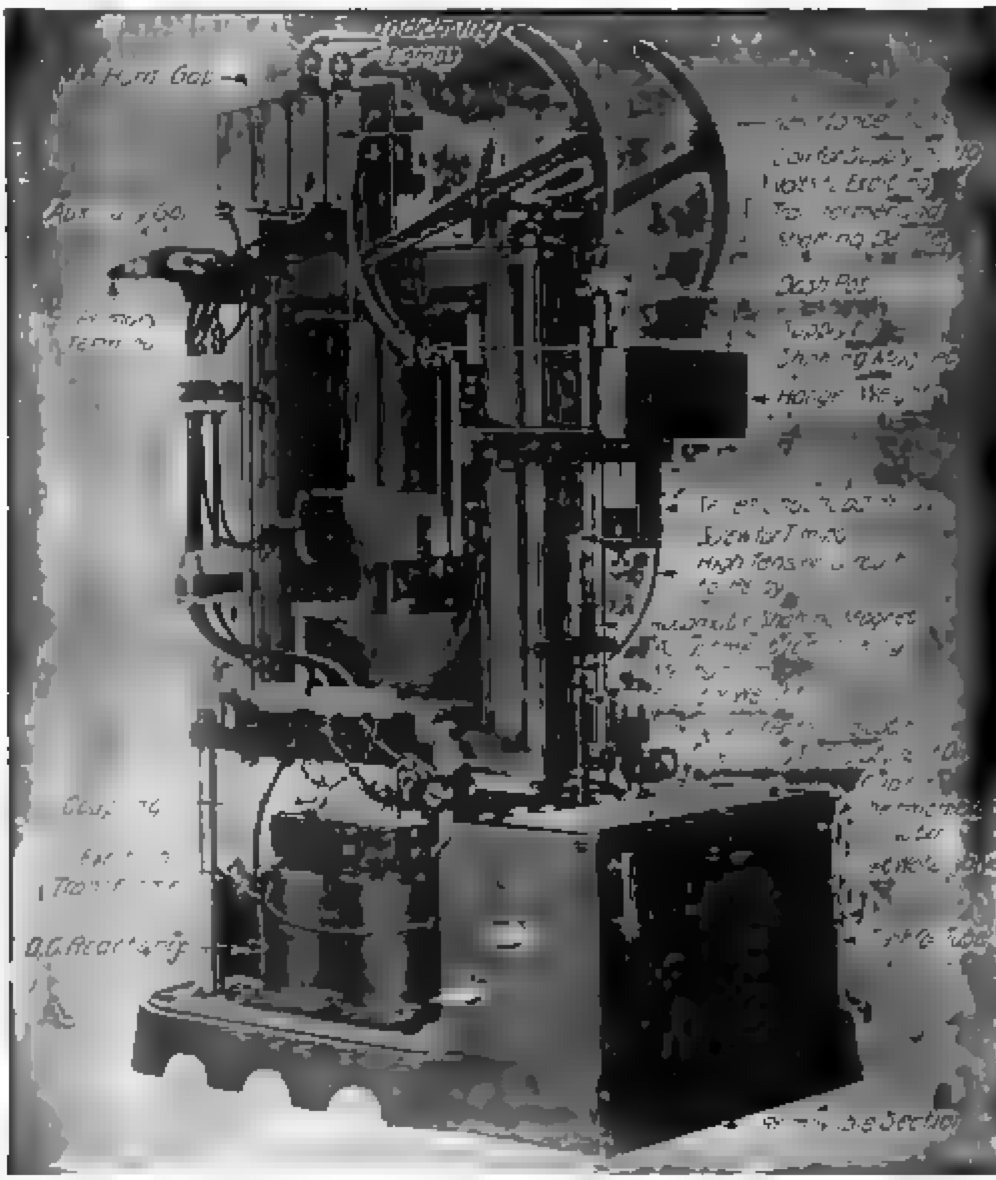
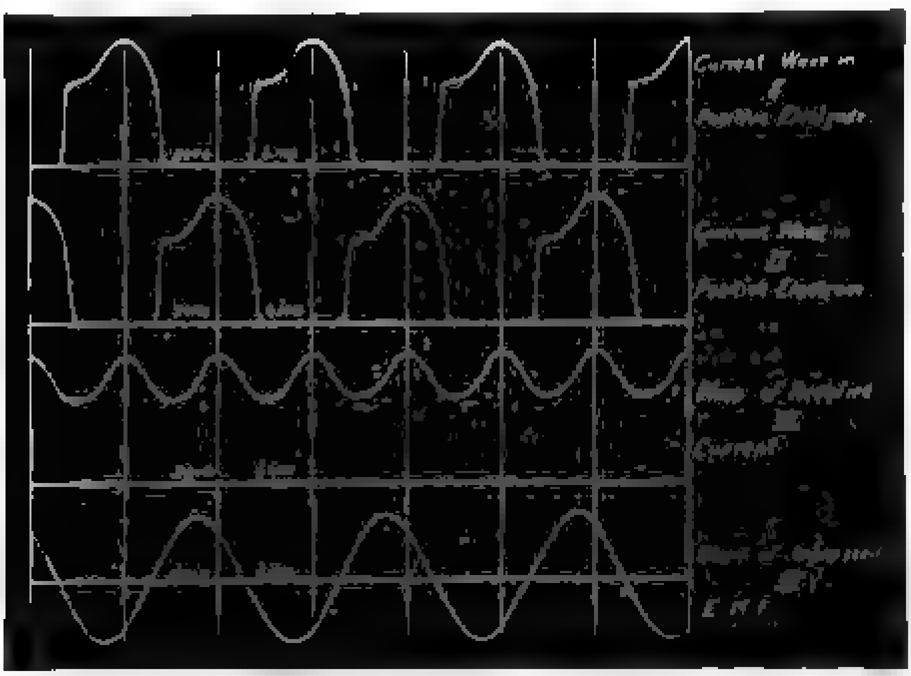


FIG. 2,102. General Electric 2,200 volts, 60 cycle, primary, 6.6 ampere, secondary, 75 light, double tube mercury arc rectifier outfit with automatic shaking device, the case being removed to show parts. The constant current transformer is air cooled. The winding which supplies energy for the exciter transformer is located at the top of, and around the core of the constant current transformer. The exciting transformer is mounted on the base of the constant current transformer inside of the casing. It supplies low pressure currents to the starting anodes of the rectifier tube. This current establishes an auxiliary arc when the tube is shaken, which is necessary in order to start the rectifier. The exciting transformer is wound for 110 volts and it consumes about 200 volt-amperes. The direct current reactance is mounted on the base of the transformer and enclosed in the same casing. It is connected in series with the lamp load and its function is to reduce the pulsations of the circuit to a value most satisfactory for operation. The tube tank for holding the oil is mounted on the same base as the transformer. It is provided with a cooling coil, a tube carrier is provided for raising or lowering the tube in the tank. A thermometer is provided to gauge the temperature of the oil in the tank. The static dischargers consisting of horn gaps in series with resistance, are connected between the anodes and the cathode in order to protect the tubes and other apparatus from excessive electrical strains. The horn gaps open the circuit after discharge, and in case the resistance becomes damaged the discharge passes across the spark gap provided, thereby shunting the resistance.

[redacted]

he part of the bulb containing the mercury, and induces static parks on the surface of the mercury which break down the ıegative electrode resistance.

The action of the rectifier will be better understood by reference to the diagram of current waves and impressed pressure as shown in figs. 2,103 to 2,106.



[redacted] to 2,106.—Diagram of current waves and impressed pressure of Westinghouse-Cooper Hewitt mercury vapor rectifier. The whole of the alternating current wave on both sides of the zero line is used. The two upper curves in the diagram show the current waves in each of the two positive electrodes, and the resultant curve III represents the rectified current flowing from the negative electrode. Curve IV shows the impressed alternating current pressure. It is evident that if the part of the wave below the zero line were reversed, the resulting current would be a pulsating direct current with each pulsation varying from zero to a positive maximum. Such a current could not be maintained by the rectifier, because as soon as the zero value was reached the negative electrode resistance of the rectifier would be re-established and the circuit would be broken. To avoid this condition, reactance is introduced into the circuit, which causes an elongation of current waves so that they overlap before reaching the zero value. The overlapping of the rectifier current waves reduces the amplitude of the pulsations and produces a comparatively smooth direct current as shown in curve III. In this way the whole of the alternating current is transformed to direct current because each of the alternations in both directions is alternately rectified.

Ques. Describe a mercury vapor rectifier outfit for eries arc lighting.

Ans. It consists of a constant current regulating transformer,

a rectifier bulb, and a control panel containing the necessary switches, meters, etc. The transformer and rectifier bulb are mounted in the same tank.

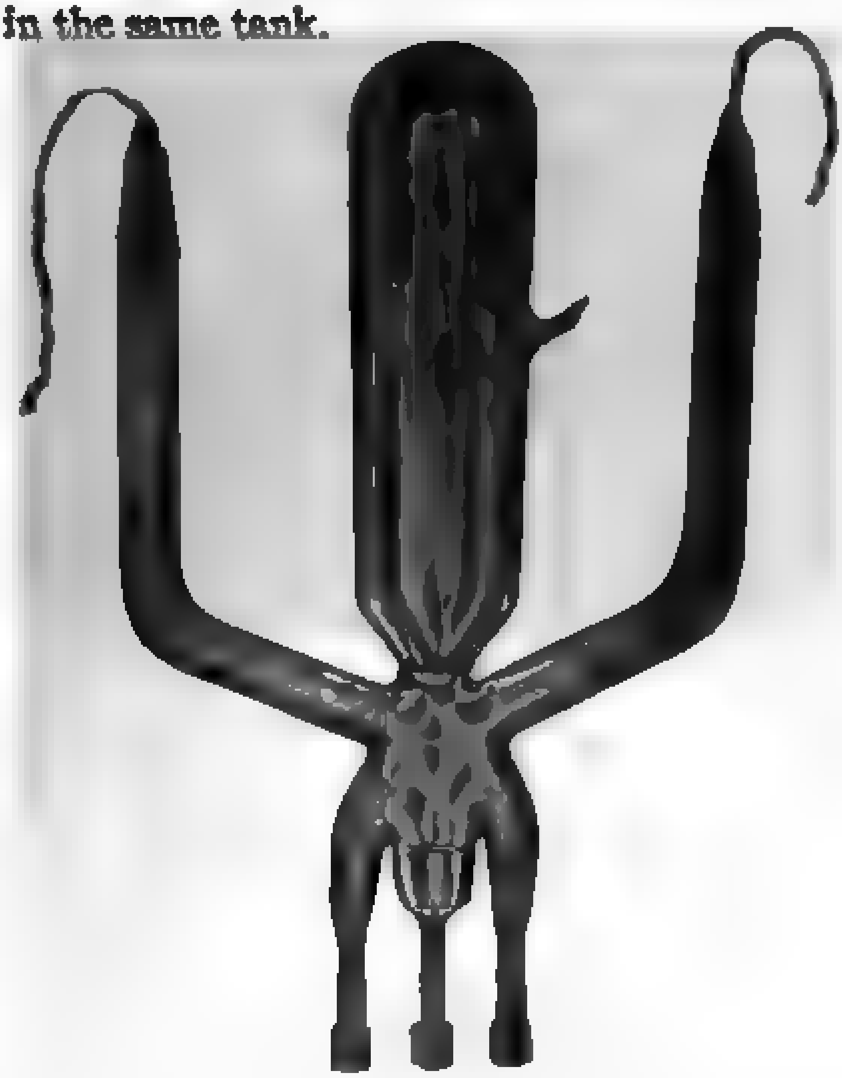


FIG. 2,107.—General Electrical rectifier tube as used on series mercury arc rectifier. The tube rectifies the alternating current into direct current. It consists of an exhausted glass vessel containing one anode or positive terminal in each of the two upper arms, two mercury starting anodes and a cathode or negative terminal of mercury at the bottom of the tube. It is submerged in oil and supported in a removable carrier. The tube is put into operation by slightly shaking it. In the combined unit set, this shaking is accomplished by an electromagnet mounted above the tube tank and operated from a pull button switch on the panel. An automatic shaker is sometimes installed which will automatically start the tube when the set is started, or if its operation should become interrupted while in service. The energy for the operation of this magnet (110 volts alternating current) is obtained from the small auxiliary winding on the main transformer which also supplies energy to the exciting transformer. The oil in which the tube is placed is cooled by a circulation of water through the cooling coils on the inside of the tube tank. The amount of water necessary for cooling the rectifier tubes varies according to local conditions, depending upon the temperature of the water and that of the air in the station but under the most favorable conditions no water is required. As rectifiers are commonly installed in steam driven stations, the drip from the tube tanks is usually piped to the boiler supply thereby eliminating any loss for cooling water.

Ques. Describe the construction and operation of the mercury arc* rectifier shown in fig. 2,108.

Ans. Fig. 2,108 is an elementary diagram of connections. The rectifier tube is an exhausted glass vessel in which are two graphite anodes A, A′, and one mercury cathode B. The small starting electrode C is connected to one side of the alternating

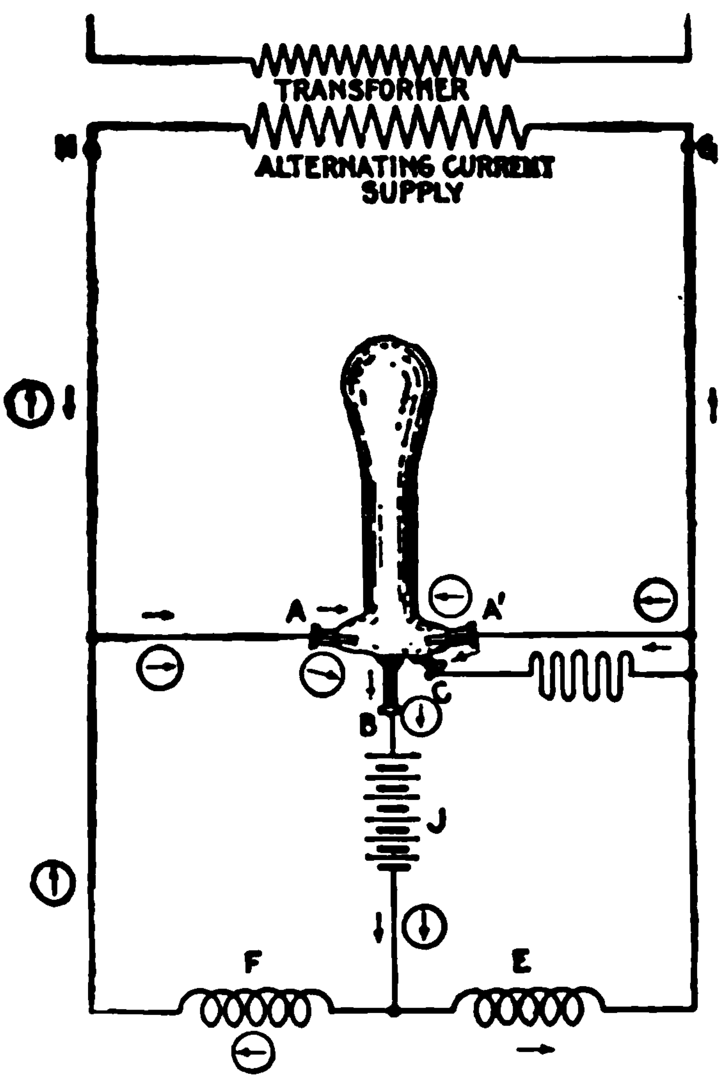


FIG. 2,108.—Elementary diagram of mercury arc rectifier connections. A.A., graphite anodes; B, mercury cathode; C, small starting electrode; D, battery connection; E and F, reactance coils, G and H, transformer terminals; J. battery.

circuit, through resistance; and by rocking the tube a slight arc is formed, which starts the operation of the rectifier tube. At the instant the terminal H of the supply transformer is positive, the anode A is then positive, and the arc is free to flow between A and B. Following the direction of the arrow still further, the

*NOTE.—The terms *vapor* and *arc* as applied to rectifiers, do not indicate a different principle; the Westinghouse Co. employ the former, and the General Electric Co., the latter.

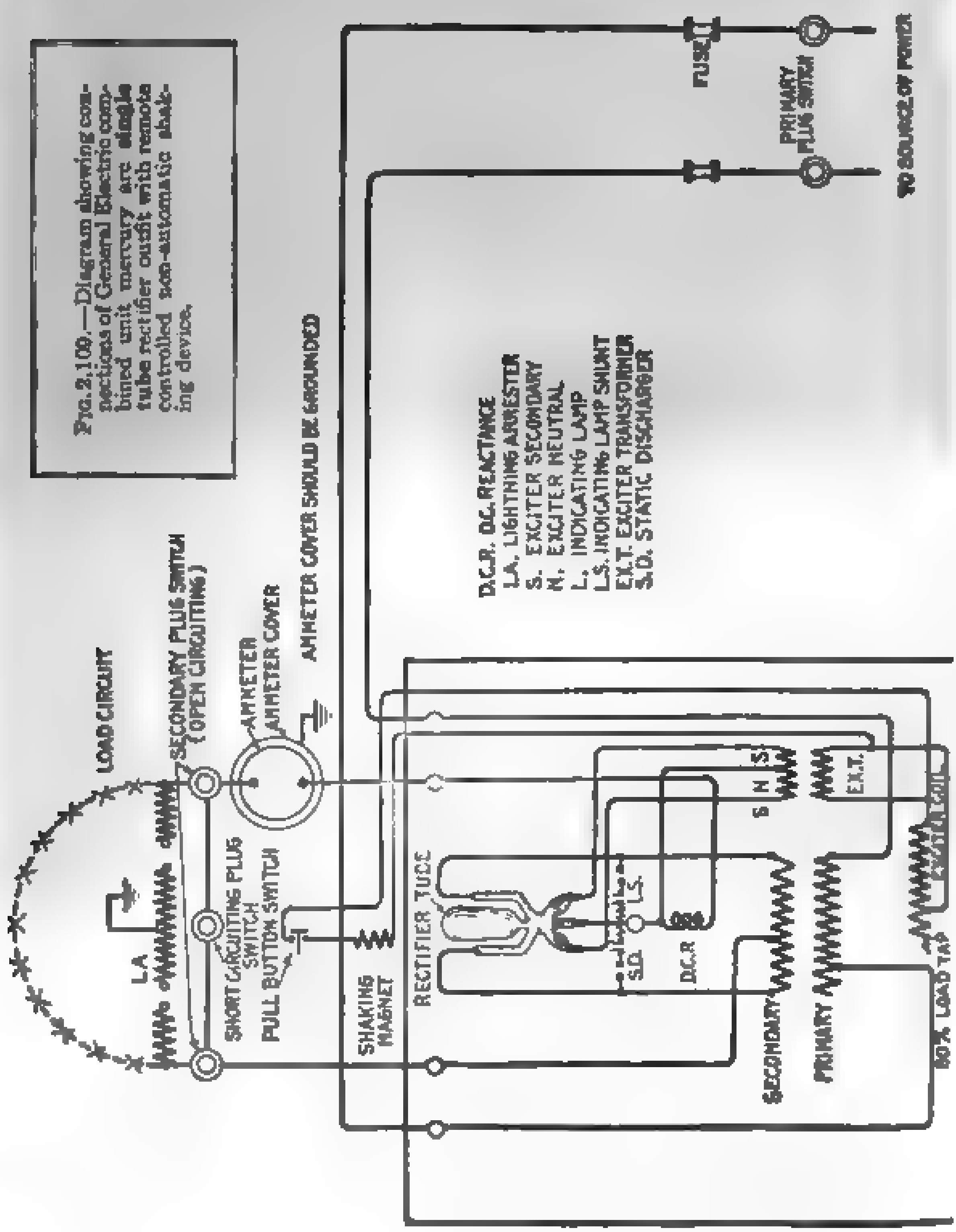


FIG. 2,109.—Diagram showing connections of General Electric combined unit mercury arc single tube rectifier outfit with remote controlled non-automatic shaking device.

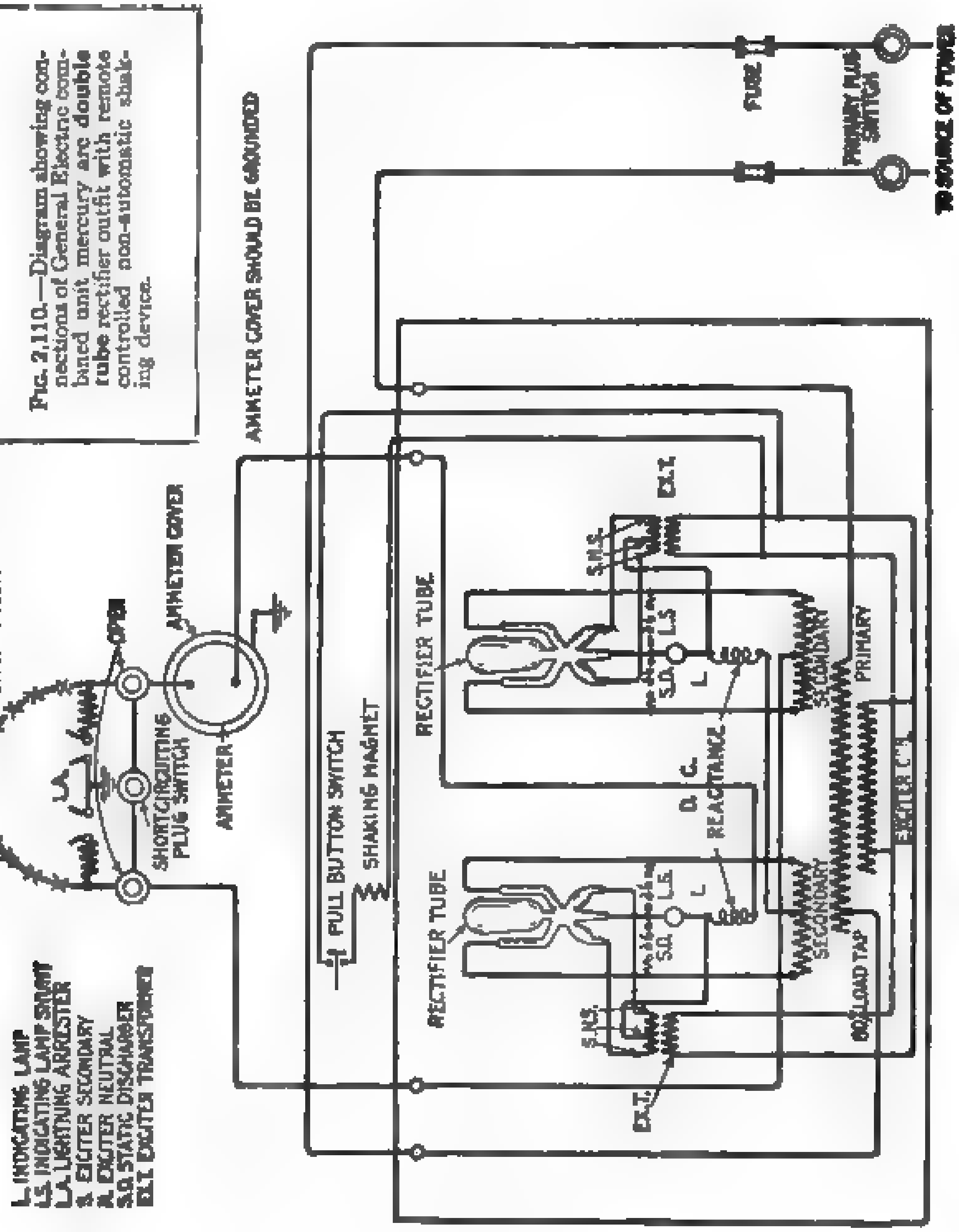


FIG. 2,110.—Diagram showing connections of General Electric combined unit mercury are double tube rectifier outfit with remote controlled non-automatic shaking device.

current passes through the battery J, through one-half of the main reactance coil E, and back to the negative terminal G of the transformer. When the impressed voltage falls below a value sufficient to maintain the arc against the reverse pressure of the arc and load, the reactance E, which heretofore has been charging, now discharges, the discharge current being in the same

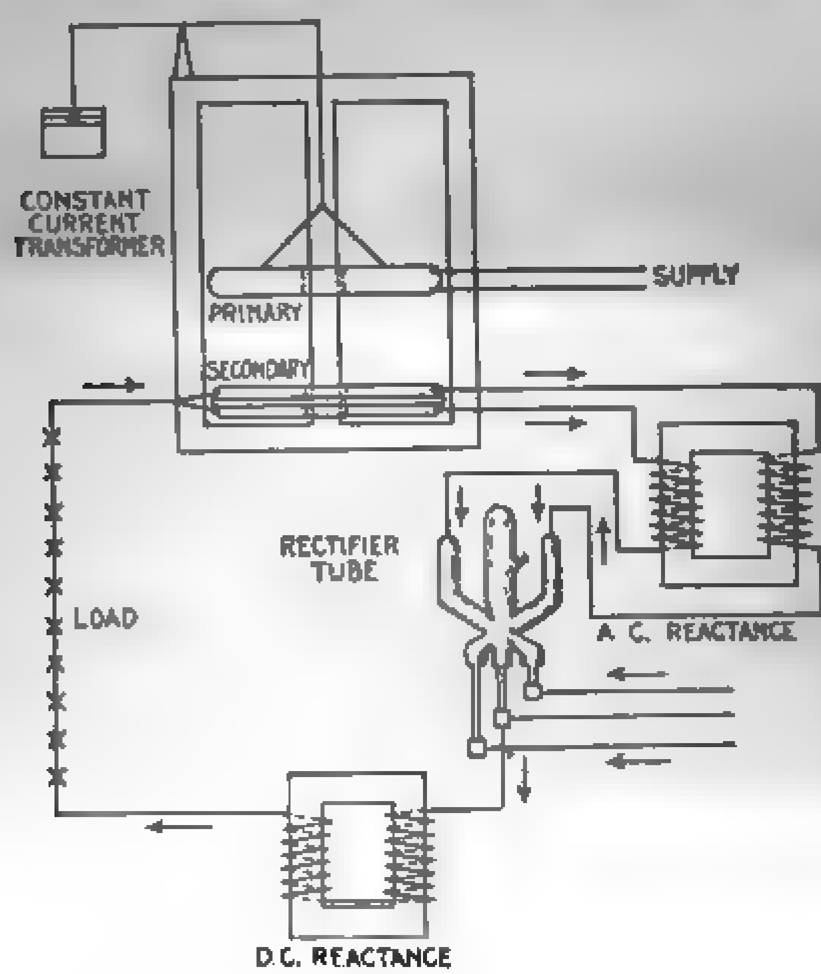


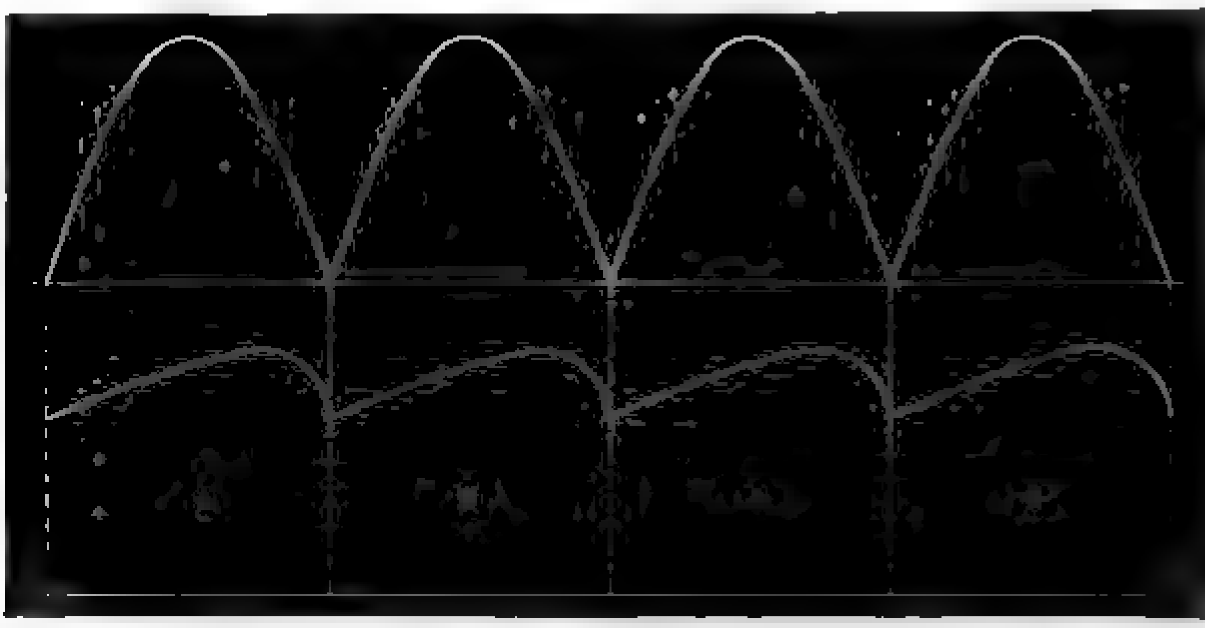
FIG. 2,111.—Diagram showing connections of General Electric series mercury arc rectifier.

direction as formerly. This serves to maintain the arc in the rectifier tube until the pressure of the supply has passed through zero, reversed, and built up such a value as to cause the anode A to have a sufficiently positive value to start the arc between it and the cathode B. The discharge circuit of the reactance

coil E is now through the arc A'B instead of through its former circuit. Consequently the arc A'B is now supplied with current, partly from the transformer, and partly from the reactance coil E. The new circuit from the transformer is indicated by the arrows enclosed in circles.

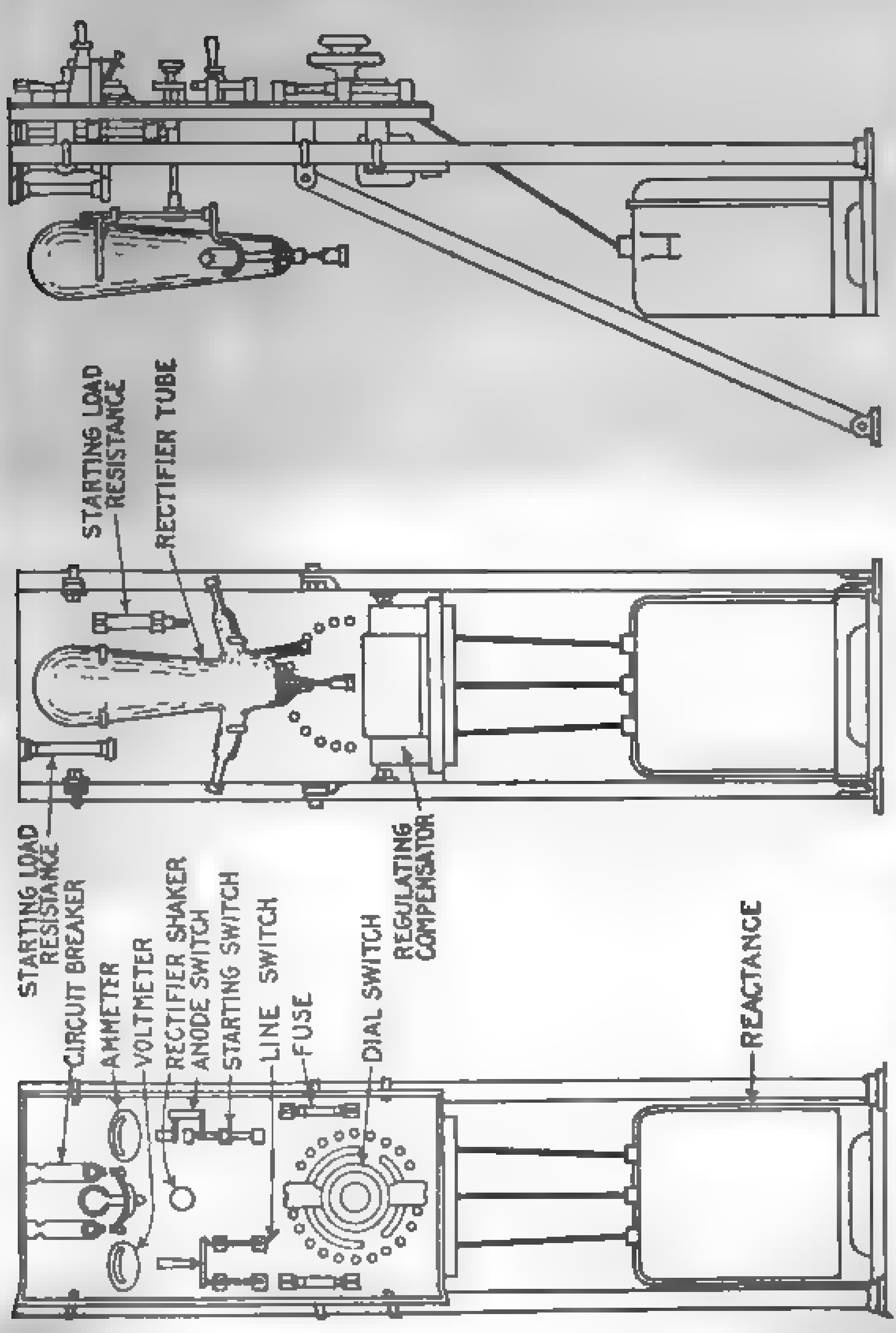
Ques. How is a mercury arc rectifier started?

Ans. A rectifier outfit with its starting devices, etc., is shown in figs. 2,114 to 2,116. To start the rectifier, close in order named



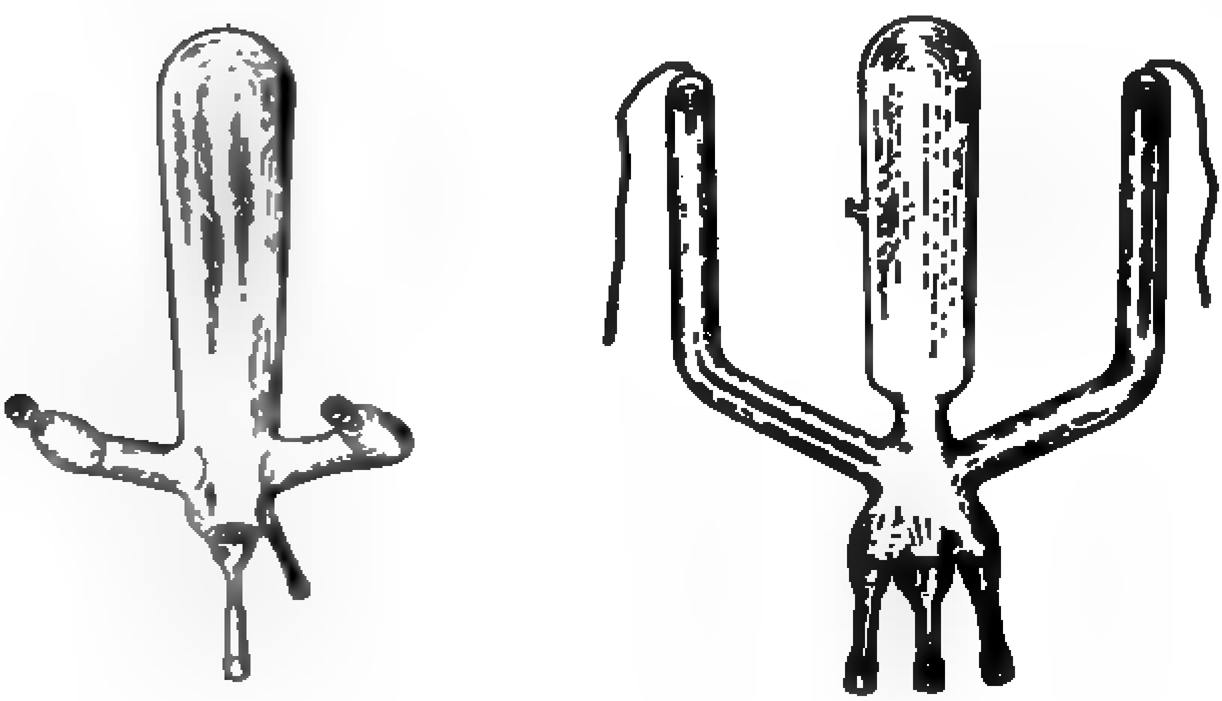
FIGS. 2,112 and 2,113.—Diagram of current waves showing effect of reactance coil. If the alternating current wave could be rectified without the use of the reactance coil, the direct current produced would consist of a series of impulses which would rise and fall from the zero line as illustrated in fig. 2,112. The action of the reactance coil not only maintains the current through the tube while the supply current is passing through zero, but helps to smooth out the pulsations of the direct current which is passing out of the cathode terminal of the tube to the batteries, or other direct current apparatus put in its circuit. The smoothing out effect of the reactance is shown in fig. 2,113. It will be seen from the diagram that the current does not drop down to zero and the pulsations of the direct current are greatly reduced. The waves A, A, etc., are from the positive waves of the alternating current supply, while B, B, are from the negative waves, and together they form the rectified current, flowing in the same direction to the external direct current circuit shown at B in the diagram, fig. 2,108.

line switch and circuit breaker; hold the starting switch in opposite position from normal; rock the tube gently by rectifier shaker. When the tube starts, as shown by greenish blue light, release



FIGS. 2,114 to 2,116.—General Electric mercury arc rectifier outfit, or charging set. The cut shows front, rear, and side views of the rectifier, illustrating the arrangement on a panel, of the rectifier tube with its connection and operating devices.

starting switch and see that it goes back to normal position. Adjust the charging current by means of fine regulation switch on the left; or, if not sufficient, by one button of coarse regulation switch on the right The regulating switch may have to be adjusted occasionally during charge, if it be desired to maintain charging amperes approximately constant.



FIGS. 2,117 and 2,118.—General Electric mercury arc bulbs or tubes for 200 and 10,000 volt circuits.

Ques. In the manufacture of rectifiers, could other metals be used for the cathode in place of mercury?

Ans. Yes.

Ques. Why are they not used?

Ans. Because, on account of the arc produced, they would gradually wear away and could not be replaced conveniently.

In the case of mercury, the excess vapor is condensed to liquid form in the large glass bulb or condensing chamber of the tube and gravitates back to the cathode, where it is used over and over again.

Ques. In the operation of rectifiers, how is the heat generated in the bulb dissipated?

Ans. In small rectifier sets the heat generated is dissipated

FIG. 2,119.—General Electric series mercury arc rectifier outfit; view showing method of replacing a tube. The illustration also shows tube carrier and drip tray.

through the tube to the air, and in large tubes such as used in supplying 40 to 60 kw. for constant current flaming arc lights operating at 4 or 6.6 amperes, the tubes are immersed in a

tank of oil, and cooled similar to the arrangement used for oil insulated water cooled transformers.

Ques. What results are obtained with oil cooled tubes?

Ans. In practice it is found that the life of oil cooled tubes is greatly increased and temperature changes do not affect the ability to start up as in the air cooled tubes.

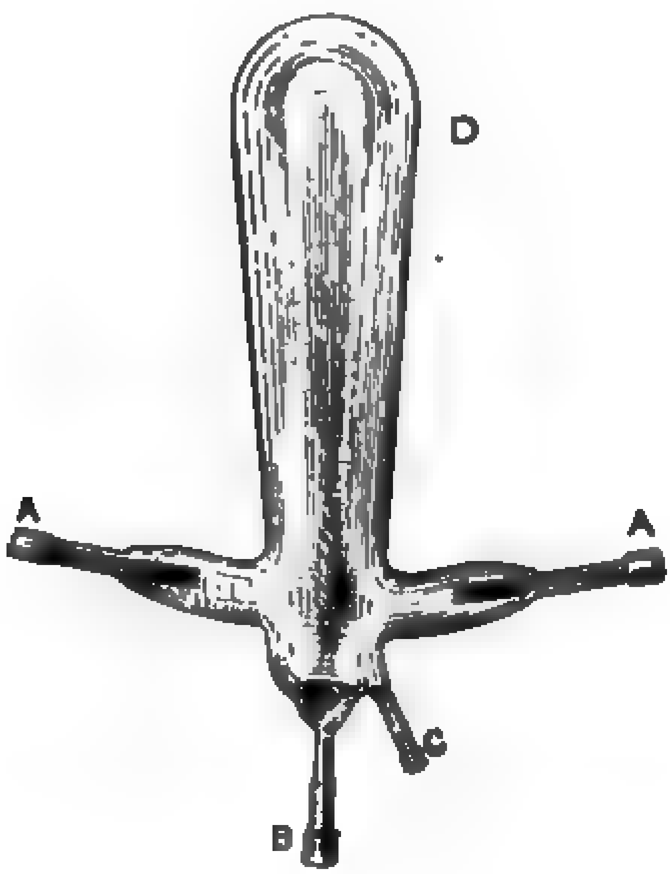


FIG. 2,120.—General Electric 100 volt mercury arc rectifier tube. A,A, anodes; B, cathode; C, starting anode; D, tube or bulb.

Ques. In the operation of a rectifier, name an inherent feature of the mercury arc.

Ans. A reverse pressure of approximately 14 volts is produced, which remains nearly constant through changes of load.

frequency, and voltage. Its effect is to decrease the commercial efficiency slightly on light loads.

Ques. What is the advantage of a rectifier set over a motor generator set?

Ans. Higher efficiency and lower first cost.

Ques. What is the capacity of a rectifier tube?

Ans. 40 to 50 amperes.

Ques. How is greater capacity obtained?

Ans. When a greater ampere capacity is required, two or more rectifier sets can be joined to one circuit.

The rectifier may be joined in series for producing an increased voltage or two tubes can be connected in series in a single set.

Ques. For what service is a rotary converter better adapted than a rectifier?

Ans. For power distribution and other cases where a great amount of alternating current is to be converted into direct current, the rotary converter or large motor generator sets are more practical.

Ques. For what service is a rectifier especially adapted?

Ans. It is very desirable for charging storage batteries for automobiles from the local alternating current lighting circuit.

When the consumer installs and operates the apparatus for his own use and wear, there is considerable saving over motor generator sets because a small one to two horse power motor generator outfit has an efficiency of only 40 to 50 per cent. while mercury vapor rectifiers will have from 75 to 80 per cent.

Ques. What precautions should be taken in installing a rectifier?

Ans. It should be installed in a dry place and care should be taken to avoid dangling wires near the tube to prevent [illegible].

puncturing. If the apparatus be installed in a room of uniform moderate temperature very little trouble will be experienced in starting, while extreme cold will make starting more difficult.

***Electro-magnetic Rectifiers.**—Devices of this class consist essentially of a double contact rocker which rocks on pivot (midway between the contacts), in synchronism with the frequency of the alternating current, so changing the connections at the instants of reversals of the alternating current that a direct current is obtained.

Fig. 2,121 is a combined sketch and diagram of connections of a type of *electro-magnetic rectifier* that has been introduced for changing alternating into direct current. The actual apparatus consists of a box, with perforated metal sides, about ten inches square and six inches deep. This box contains the step down transformer P,S,S′, and the condensers K and K′, the magnets and contact making device about to be described being fixed on the polished slate top of the box, exactly as shown in the figure. The transformer primary winding P may be connected through a switch *s* with a pair of ways on the nearest distribution box, or to a plug connection or lampholder, and the apparatus will give a rectified current of 6 or 12 amperes at 20 volts, according to the size.

S and S′ is the secondary winding of the transformer, with a tapping *t* midway, joining it to a series circuit containing two alternating current electro-magnets E and E′, whose cores are connected by the long soft iron yoke Y. Pivoted at P′ is a steel bar SB, which is polarized by the two coils C and C′ the current being supplied by a cell A. Fixed

*NOTE.—The Edison electro-magnetic rectifier is described in detail in Guide No. [illegible], pages 942 to 945.

rigidly to SB, and moving with it, is a double contact piece CP with platinum contacts opposite similar ones on the fixed studs CS, CS′.

CP is flexibly connected through F to one of the direct current terminals T, to which also are joined up one coating of each condenser K and K′.

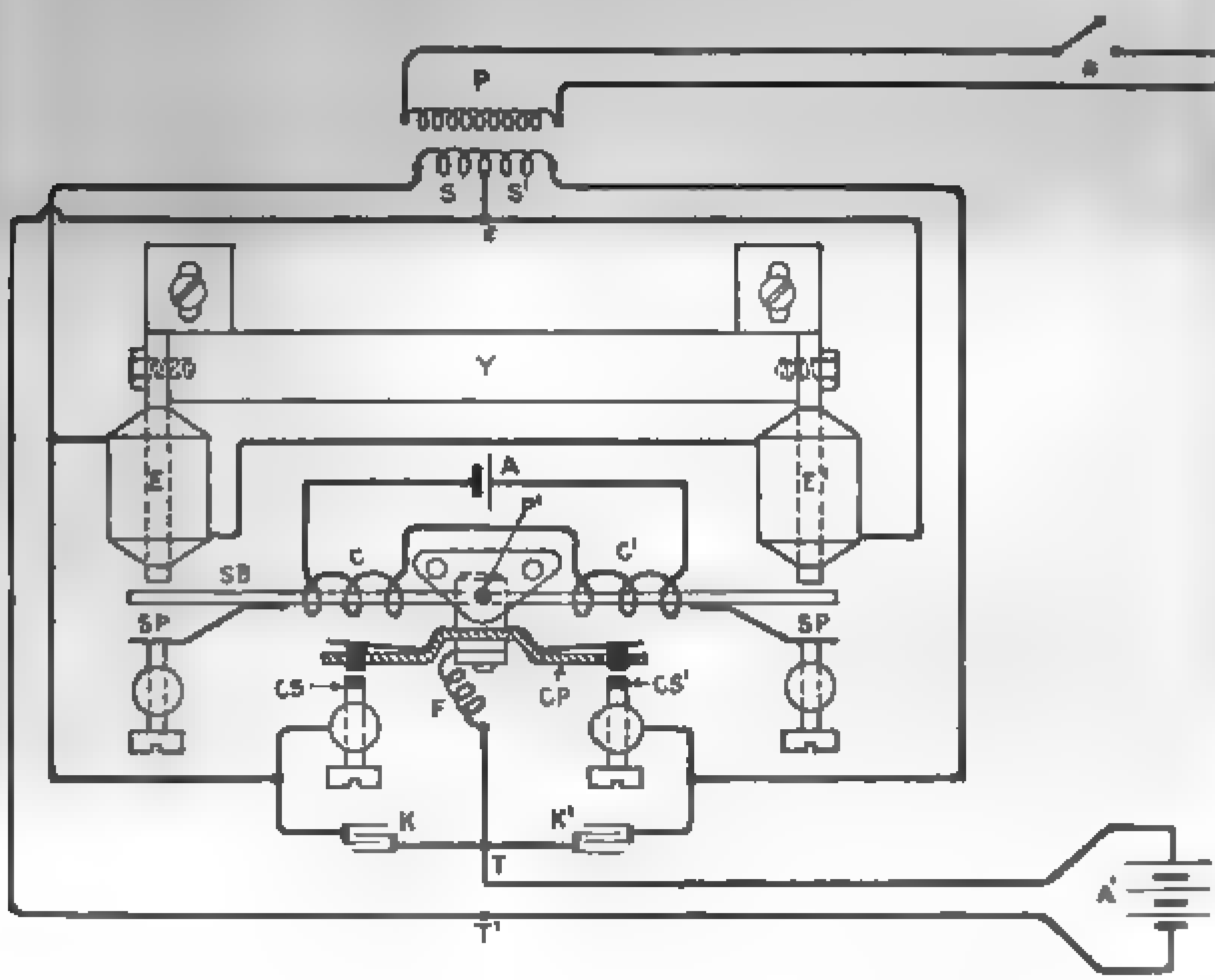


FIG. 2,121.—Diagram showing essential features of Premier Ampero electromagnetic rectifier. Details of construction and principles of operation are given in the accompanying text.

The other direct current terminal T′ is connected to the center of the transformer secondary at *t;* and CS and CS′ are respectively joined up to either end of the secondary winding and to the other coatings of the condensers.

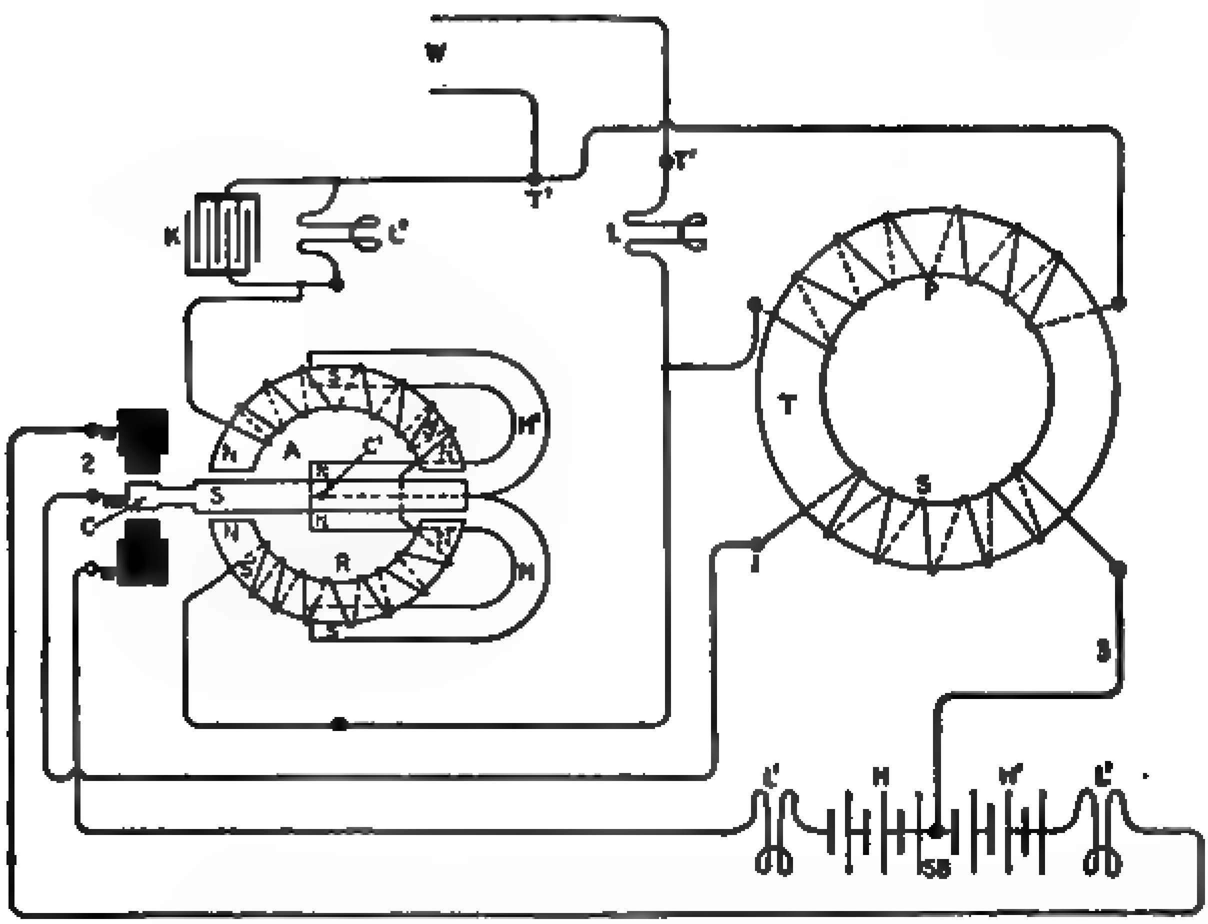


FIG. 2,122.—Diagram of General Electric (Batten) electro-magnetic rectifier. It is desirable for light and occasional service, where direct current is required but only an alternating supply is available, being used for charging storage batteries, exciting spark coils, performing electrolytic work, etc. The rectifier consists of a step down static transformer T, by means of which the circuit pressure is reduced to about 50 volts; also, a polarised relay R, the contact tongue C of which moves to one side or the other in sympathy with the alternations of the current in the primary winding P, the secondary current induced in the winding S being thereby rendered direct in the outer circuit. T', T' are the main terminals which are connected to the alternating current supply through the wires W. Lamps inserted at L are used as resistances in the primary circuit, the reduction of the voltage already alluded to being effected by this means. In charging storage batteries where a low pressure is required, a lamp (or lamps) should be connected in the secondary circuit as shown, S B being the storage battery, and L' L' the lamp resistances in series therewith, the battery has one end of the secondary S connected to its middle. Thus the alternating current leaving the transformer by the wire 1, passes by flexible connection 2, to the vibrating contact tongue C of the relay, the latter causing the currents in either direction to flow through the two halves H, H' of the battery, whence the current re-enters the secondary of the transformer by the wire 3. The soft iron core of the relay is in two halves S' S' and the armature A, carrying C, vibrates between their polar extremities. M, M' are two permanent magnets with their like poles together at the center C' where A is pivoted. Supposing these poles are north as indicated, the extremities of A will be south. The south ends of M, M being in juxtaposition with the centers of the soft iron cores S', S' will render their extremities facing the ends of A of north polarity. The windings on S', S' are connected in series with each other, and in shunt with P across the main terminals T', T'. Then because of the polarisation of A and S', S', the former will vibrate rapidly in sympathy with the alternations of the current. K is a condenser shunted by a lamp resistance L'', this being found to improve the working of R.

When the alternating current circuit is broken, the springs SP, SP, carried by SB and bearing against the adjustable studs, keep SB, CS and CS′. The apparatus thus acts also as a *no voltage circuit breaker*, for should the supply fail, the storage battery A′ under charge will be left on open circuit.

The action of the device is briefly as follows:

Owing to the direct current in the magnetizing coils C and C′ one end of SB will be permanently of north and the other of south polarity; and since the polarities of the poles E and E′ will alternate with the alternations of the transformer secondary current, SB will rock rapidly on its pivot, and contact will be made by turns with CS and CS′.

The purpose of the condensers K and K′ is to reduce the sparking at these points. When contact is made at CS, the direct current terminals T and T′ are connected to the S half of the secondary winding; and when contact is made at CS′, they are connected to the S′ half. Thus a rectified unidirectional current will flow from T and T′, and it may be used to charge the battery A′, work a small motor or for various other purposes requiring direct current.

When the rectifier is used for charging storage batteries, the separate cell A may sometimes be dispensed with, the winding C,C′ being connected to one of the cells under charge.

The rectifier is adjusted to suit the frequency of the supply circuit by altering the distance of the poles of E and E′ from the ends of the polarized armature SB; and also by changing the tension of SP, SP by means of the screw studs against which they bear.

[redacted]